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FINAL REPORT

ONR/HUGHES HIGH SPEED TOWED ARRAY SYSTEM (HSTAS)

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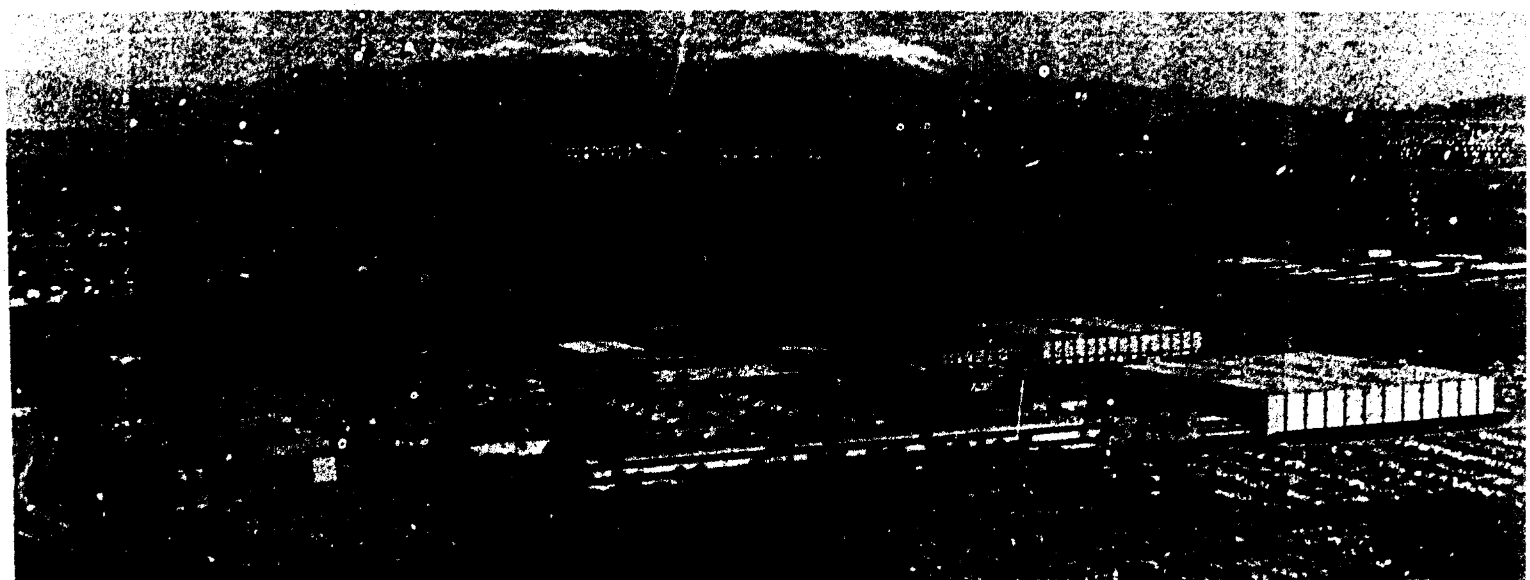

FINAL REPORT
ONR/HUGHES HIGH SPEED TOWED ARRAY SYSTEM (HSTAS)

(Reporting Period Ending September 1977)

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TABLE OF CONTENTS

LIST OF FIGURES

I. SUMMARY

During the reporting period (FY 1977), a High Speed Towed Array System (HSTAS - see Figure 1) was conceived, designed, and fabricated. The system was successfully sea tested in July of 1977 in Exuma Sound in the Bahamas aboard the R/V Harris.

In addition to the test being successful from the point of view of equipment operability at sea, the following program goals were achieved:

(a) The self noise results (shown in Figures 22-26) revealed that the 6 inch diameter module (FAM) was always quieter than the 3 inch modules, reaching a peak differential of approximately 15 dB in the frequency range between 80 Hz and 250 Hz at 18 knots towspeed (Figure 26). This general trend, which has been verified experimentally, tends to support the theory set forth by Chase[1] in reference to the dependence of array self noise on diameter (see Section IV).

(b) The demonstration (at sea) of the ability to eliminate ownship radiated noise interference from beam outputs by means of an adaptive filter employed as a noise canceller. Specifically, in the case of a broadband interfering signal, a maximum cancellation of 15 dB was achieved (Figure 32), while for the narrowband case the cancellation was 18 dB (Figure 33). For this latter effort, the R/V Harris was augmented acoustically by towing the HX-90 noise source.

(c) Extensive data gathering (tape recordings) occurred during the sea trial (channel outputs, beam outputs and time multiplexed channel data) which permitted a post sea test improvement/evaluation of the noise canceller

hardware and software. This latter effort disclosed programming errors, which when corrected resulted in an increase of the cancellation capabilities from the values cited above to approximately 23 dB broadband (Figure 34) and in excess of 25 dB narrowband (Figure 35).

The array self noise and the noise canceller results taken together thus provide a systems approach to the problem of utilizing a towed array behind a high speed platform which injects large amounts of acoustic energy into the water. Further testing and evaluation of the system at higher tow speeds is necessary to demonstrate the effectiveness of the HSTAS concept.

II. GOALS

The goals of the program have been the following:

(a) Design, fabricate, assemble and sea test a high speed towed array system capable of operating at speeds in the vicinity of 35 knots.

(b) Acquire self-noise data from two different diameter hoses in the same array (3 inch and 6 inch).

(c) Demonstrate the operation of an adaptive noise canceller configured to operate in the Post Beamformer Interference Cancellation (PIC) mode to reduce ownships noise so that array self-noise levels can be measured at high speed.

NOTES: 1. All three goals were met during the July 1977 Sea Test within the operational constraints of the R/V Harris.

2. Goal (b) above requires some added detail. Although it would have been desirable to not only demonstrate the relative difference in self-noise performance between the two hose diameters but also to have the lowest (quietest) configuration available, this was not possible due to economic considerations. More specifically, the cost of acquiring a 6 inch diameter hose utilizing the "state of the art" hose-wall was beyond the fiscal reach of the current program. Thus, it was decided to forego the absolute performance and focus only on the relative effect of diameter. This was achieved by fabricating all the acoustic module hoses from rubber rather than PVC which is known to produce lower self noise levels at the water temperatures of Exuma Sound.

III. ADMINISTRATIVE INFORMATION

The High Speed Towed Array System (HSTAS) shown in figure 1 is the result of a cooperative funding effort between the Navy (ONR) and Hughes Aircraft. More specifically the principal components of the system had the following sources of support:

Component	Source
1. Towed Array	ONR (GFE Telemetry from PME 124)
2. Tow Cable	GFE-NUSC/NLL
3. Receiver	GFE-PME 124
4. Beamformer	Hughes
5. MINIPRO — Adaptive Noise Canceller	Hughes

The ONR funded portion of the HSTAS Program (towed array) was carried out under Contract Number N00014-71-C-0223 Mod. P00014 (8 March 1977). The Hughes hardware (Beamformer and MINIPRO) was developed under the Hughes Aircraft IR&D Program in the area of Passive Sonar Development prior to the award of the ONR Contract.

The program sponsor was Mr. G. Boyer of ONR Code 222. The program at Hughes was managed by Mr. S. Berlin of the Data Processing Products Division of the Ground Systems Group at Fullerton, California. Valuable assistance was provided by Mr. J.S. Diggs of MAR Incorporated in Rockville, Maryland.

IV. THEORETICAL CONSIDERATIONS

In Section II, Goals; goal (b) was to "acquire self-noise data from two different diameter hoses in the same array (3" and 6"). The motivation for this goal originated in a desire to verify experimentally the theoretical predictions of Chase[1] regarding the dependence of towed array self-noise on hose diameter.

The self noise level perceived by the hydrophone is due (neglecting tow cable strum and array free-end effects) to the turbulent boundary layer on the exterior surface of the hose. This boundary layer has a power spectral density distribution that is continuous in wave number $k = 2\pi/\lambda$. However, following Reference 1, three regions of this spectrum are identified for study in connection with the present problem. They are:

1. Convective component $\left(k \approx \frac{\omega}{U}\right)$
2. Resonant wavenumber component $\left(k_r \approx k_r(\omega)\right)$
3. Low wavenumber component $(ka \leq 1)$

where: k = wavenumber $= \frac{2\pi}{\lambda}$

$\omega = 2\pi f$ = frequency

a = Hose wall radius

Subscript r = Denotes hose-fluid resonance

U = Towed array velocity

The first component mentioned above occurs in the frequency region of the boundary layer spectrum where most of the energy is. However, for a towed array in which the scattering is minimized by reducing the size of interior components, the contribution from the convective term becomes negligible as explained in Reference 1. To be more specific, the convective component of the flow noise spectrum is proportional to:

$$\left(\frac{U}{C_r}\right)^4$$

where: $C_r = \left(\frac{Eh}{2\rho}\right)^{1/2} \quad \left(\frac{2\Delta a}{a}\right)^{1/2}$

where: U = Tow velocity

E = Elastic modulus (hose)

h = Hose wall thickness

Δa = Distance from boundary layer to sensor

a = Hose radius

ρ = Fluid density

The FAM (Figure 9) configuration shown in cross-section is a practical example of an attempt to achieve a low scattering cross-section.

The second component of the turbulent boundary layer spectrum, the energy at resonant wave numbers (k_r) is also shown in Reference 1 to be a negligible contributor to the noise level perceived by the hydrophone. In this case the level transmitted through the hose is shown to be[1] proportional to:

$$\frac{1}{\zeta C_o}$$

where: $C_o^2 = \frac{Eh}{2\rho}$ and ζ = Hose loss tangent (damping).

Finally, the third region of the boundary layer spectrum (low wave numbers) is the one that would be expected to contribute most significantly to the noise level at the hydrophone in the absence of scattering. The contribution of this component is also inversely proportional to ζ and C_o as was the case for the resonant component.

Furthermore, in reference 2 the dependence of the low wavenumber component of the boundary layer pressure field on hose radius is given by the following expression:

$$k \propto a^{-4} U^{8} \omega^{-5}$$

Thus, a doubling of the hose radius (a) would be expected to result in a 12 dB decrease in hydrophone self-noise if it is due largely to the low wave number component of the pressure field.

It is to be emphasized that the foregoing brief summary of the theoretical model of towed array self noise applies to the case of a low scattering configuration only. The FAM cross-section shown in Figure 9 does indeed approximate this latter ideal. The control modules however (Figure 4), were more densely packed with respect to the effective scattering cross-section of the interior components. Perfect scaling between the FAM and control modules did not exist because the funding did not allow for geometrically scaled electronics and hydrophones to be acquired. The hose diameter, wall thickness and reinforcing cord arrangement were scaled in the ratio of 2 to 1 (FAM to Control). Further experimentation and analysis will be needed to fully resolve the question of what the impact of the lack of complete scaling is on the measured data.

Figure 2 is a plot extracted from reference 1 which summarizes Chase's predictions about the effects of diameter on towed array self-noise levels. On this figure, the pertinent cases are labelled "0" and "1" with each group of three curves corresponding to a different towing speed (15, 30 and 60 knots).

The work being reported on in this final report had as one of its goals an experimental assessment of the predictions briefly reviewed above. In order to measure the flow noise, the biases injected by a high speed tow ship have to be removed. The adaptive canceller to do this is discussed in Section V. B. 3.

V. SYSTEM DESCRIPTION

The High Speed Towed Array System consisting of a towed array, tow cable, telemetry receiver, beamformer, noise canceller and data reduction and recording equipment is shown schematically in Figure 1. The system functions include:

(a) Provision for simultaneously acquiring data from two different diameter towed array modules (FAM and Control Modules).

(b) Provision for forming beams from an array with a design frequency 50% higher than current tactical arrays. The reason that a higher design frequency is desired for the HSTAS is that as tow speed increases, the self noise of the array builds up most rapidly at the low frequency end of the spectrum, moving higher in frequency as the tow speed is increased. Thus, one will have to rely on higher frequency radiated target energy for detection. This is illustrated in Figures 22 to 26. The lowest self noise levels will occur at the higher frequencies and therefore the design frequency (frequency of maximum gain against ambient noise) is increased relative to a lower speed system. Twenty single-hydrophone channels are used for beamforming in the HSTAS. The number twenty is a compromise between beamwidth (6^{o} at broadside) and hardware complexity both in the array and in the beamformer. Multi-hydrophone groups are often used to provide some gain against flow noise. However, this gain varies with speed and frequency and introduces still another variable into a relative (3 inch vs 6 inch) measurement experiment like the present one. Therefore, the reason for using single hydrophones (as opposed to groups of 2 or more) is twofold:

(i) To avoid any ambiguity about group gain as a function of speed, frequency and array location.

(ii) Space limitations within the array because the higher design frequency results in smaller distances between channels (see Figure 8).

(c) Provision for experimentally evaluating two types of hydrophone mounts within the FAM as shown in Figure 10.

(d) Provision for making accelerometer measurements to quantitatively assess the vibration levels in the array as a function of speed, frequency and location (see Figure 21).

(e) Provision for monitoring the electronic noise of the array by installing pressure insensitive capacitors in the FAM.

(f) Incorporation of an environmental module (see Figure 1) to measure array depth and tension under tow so that the theoretical hydrodynamic calculations could be checked.

(g) Provision for assessing inter-hydrophone correlation by having several different spacings between elements (see Figure 21).

Thus, the HSTAS design represents an effective tool for investigating the relative flow noise levels under various combinations of environmental conditions.

The primary components of the High Speed Towed Array System (HSTAS) are shown schematically in Figure 1. For the sake of clarity the following descriptions will be divided into two parts; the towed array and the shipboard electronics.

A. The Towed Array

The towed array consists of the eight separate modular components listed below:

	Module/Component	Remarks
1.	Environmental Module (P, T)	Hughes supplied
2.	Forward VIM	GFE-NUSC/NLL
3.	Forward Control Module	New
4.	Forward Transition Element	New
5.	Fat Array Module (FAM)	New
6.	Aft Transition Element	New
7.	Aft Control Module	New
8.	Aft VIM	GFE-NUSC/NLL

1. Environmental Module

This was adapted from an array fabricated previously by Hughes and was designed to sense static pressure (depth) and tension at the nose cone while towing.

2&8. Forward and Aft VIMS

These items were borrowed from Dr. A. E. Markowitz of NUSC/NLL who had fabricated them in connection with the STAMM Program. They are fully documented in reference 3. Their seaworthiness and vibration isolation (low frequency) capabilities were verified during the sea test described in the cited reference.

3&7. Forward and Aft Control Modules

These items were designed and fabricated specifically for the HSTAS. Their purpose was to provide a 3 inch array for comparison within the array with the 6 inch diameter (FAM) self noise levels. Control modules were placed in front of and behind the FAM in order to verify that the change in array diameter had no impact on self-noise levels, which it did not. Figure 3 is a photograph of the interior of one control module showing six single channel telemetry cans, four single element hydrophones and two accelerometers (one on each module bulkhead). Also visible in this photograph are the strength members, coaxial cable and individual sensor leads. Figure 4 is a view of the cross-section of a control module at the location of a hydrophone* installation. Visible in this latter photograph are the hydrophone mount, hydrophone, strength members and reinforcing fabric in the hose wall.

The hose wall of the control module was designed to be exactly one-half the thickness and contain one-half the amount of reinforcing cord that the FAM hosewall does. The rationale for the simple factor of two was to allow for the theoretical determination of the effects of diameter and hosewall thickness to be made as explained in Section IV. The engineering details (diameter, wall thickness, material and reinforcing structure) of the control module hose are shown on Figure 4 which is the drawing from which the hose was fabricated by the vendor (American Rubber Company of Oakland, California).

*The hydrophones utilized in the HSTAS were manufactured by EDO Western, Salt Lake City, Utah with a nominal sensitivity of -187 dBV re1μPa and a nominal capacitance of 1000 pf.

4&6 Forward and Aft Transition Elements

Since the HSTAS towed array has two different diameter (3" and 6") modules in it, it is necessary to provide a hydrodynamically smooth transition a. both ends of the Fat Array Module (FAM) as shown schematically in Figure 1. The transition design was not separately evaluated due to a lack of time and funds. It is the result of the collective engineering judgment of Dr. P. P. Rispin of DTNSRDC, ONR, MAR, Inc. and Hughes.

The transition elements are shown in Figure 6. The lateral surface of these members is rubber and they are liquid filled (fill fluid) in order to ensure uniform neutral buoyancy. Figure 7 is the engineering drawing that defines the transition elements in detail.

5. Fat Array Module (FAM)

The FAM contains most of the data channels of the array (27 in all of which 20 were used for beamforming, 5 for correlation studies, and two for capacitors - the array layout is discussed more fully in Section VII). Figure 8 is a photograph of the interior details of the FAM. Visible in this photograph are the single channel telemetry cans, hydrophones and mounts (two types for comparative evaluation), strength memoers, coaxial and sensor cabling the module bulkheads. The hydrophone mounting scheme used in most of the FAM data channels is shown in Figure 9, and Figure 10 shows the two types of hydrophone mounts compared in the FAM; the soft polyurethane spider and the open cell reticulated foam. The FAM hose is shown next to the control module hose in Figure 11.

In Figure 12, a detailed view of the FAM bulkhead, strength member termination and typical hydrophone mount is shown.

The FAM hose was designed to be twice as large as the control module hoses (in diameter, wall thickness and amount of reinforcing cord) and to utilize the same rubber compound (butyl). These details are shown in Figure 13 which is the engineering drawing for the FAM hose fabrication.

B. Shipboard Electronics

The shipboard electronics (see Figure 1) portion of the HSTAS (excluding data reduction equipment aboard the R/V Harris) consists of the following principal components:

Component	Remarks
1. Telemetry Receiver	GFE-PME 124
2. Beamformer	Hughes
3. Adaptive Noise Canceller	Hughes

1. The Telemetry Receiver

The telemetry receiver shown in Figure 14 is the Double Side Band Amplitude Modulated (DSAM) receiver cabinet designed for what was known as the XTASS Program. Both the telemetry transmitters (in the array) and the receiver cabinet came from XTASS via PME-124. It should be emphasized that the telemetry transmitters and the receiver were designed (several years ago) as a towed array system.

The primary function of the receiver is to demodulate the frequency multiplexed RF carriers (one for each data channel) and produce individual data channel audio outputs at about 1 volt rms. At the receiver output the individual data channels can be recorded and/or sent to the beamformer for spatial processing (beamforming). The receiver cabinet also contains the array power supply.

2. Beamformer

At high towing speeds, a towing platform such as the R/V Athena will inject large amounts of acoustic energy into the water in the frequency band of interest (nominally 10-2000 Hz). Thus, even though the towed array is displaced several thousand feet aft of the towship by the tow cable there is still a high probability that the hydrophone channel outputs will be dominated by ownship radiated noise at most, if not all, speeds. A dynamic range analysis revealed that even with the radiated noise levels of the R/V Athena, the system would remain well below overload (saturation). Assessment of the acoustic performance of the towed array would not be possible without the ability to form beams and thus steer away from the ships radiated noise field.

Besides reducing towship noise, the beamformer provides an improvement in signal-to-noise ratio (beam output vs. single channel) due to the process of summation in which both a spatial and temporal averaging of the noise field occur, i.e., rejection of ambient noise and processing aginst flow noise.

The beamformer designed for the HSTAS is shown functionally on Figure 15 and was fabricated by modifying a beamformer built for the Ships Towed Underwater Detector (STUD) Program several years ago.

Referring to Figure 15, the array interface function provides the CGA (controlled gain amplification) and delta-modulation of the 20 hydrophone signals received from the receiver cabinet. Here the data is converted from analog to digital for digital processing. The RAM beamformer performs the function of delaying the array channel signals such that they add in phase to generate a maximum response axis for a particular steering direction. The RAM beamformer provides preformed beams at angles determined by the arc sine of multiples of 1/10 (1/10, 2/10, . . . 10/10) in two quadrants, plus one broadside beam for a total of 2 x 10 + 1 = 21 beams at a -3 db crossover.

The HSTAS beamformer utilizes the outputs of the 20 hydrophone channels in the FAM (spaced at 2.5 feet) to form 21 beams with either uniform shading or Taylor shading for -35 db side lobes. Figure 16 summarizes the MRA's (Main Response Axes) and angular coverage of the HSTAS beam pattern (which is symmetrical about the broadside beam).

The following hardware modifications (to the STUD configuration) were required in order to adapt the beamformer to the present application in a cost effective manner:

- Design frequency increase by a factor of 3/2 due to the more closely spaced hydrophone channels.
- Clock frequency increase of 1.25 due to the changes in the design frequency and the number of beams.

- Reduction in the number of preformed beams from 25 to 21 (hardware economy).
- Reduction in the number of steered beams from 2 to 1 (hardware economy).
- Deletion of the broadband processor (not required in present application).
- Modernization of the control logic utilizing PROMS (firmware) in order to facilitate any further changes in the future.
- Rewiring of the "back-plane" and the use of a new beamformer mechanical chassis (ease of assembly and checkout).

The foregoing modifications did not decrease the beamformers capability but rather tailored it to the needs of the HSTAS.

An important feature of the beamformer is what is known as the array simulator. This supplies the beamformer with signals that simulate the presence of a target on any given bearing and also the ability to move the target (in azimuth) in steps of approximately 1.5°. The simulated target consists of one or more tones superimposed upon a noise background with a sea state slope (6 db/octave).

The complete beamformer (and adaptive noise canceller) is shown in Figure 17 as it was on the R/V Harris during the July 1977 sea trial.

3. Adaptive Noise Canceller

The objective of incorporating an adaptive canceller into the beamformer is to obtain unbiased flow noise measurements on the Fat Array Module in the presence of a very noisy tow ship at high tow speeds. The canceller is described and analyzed in References (6-16). The basic principle is to obtain a measured reference that is highly correlated with the interference component in a signal channel. The measured reference is used as the input to an adaptive filter which iterates to converge to minimize the power in the cancelled output. Figure (18) shows a block diagram of this function. The adaptive filter responds to the correlated components in the reference and the signal channel, and attempts to maximize that correlation and its output. If the interference is the only correlated component, then it is subtracted out in the minimum mean square error sense. If there is signal cross-talk in the reference channel, then the adaptive filter will respond to the signal correlations as well. Some bias can therefore be introduced in the event that a "clean" (signal free) reference is not available. This effect is studied in Reference (14).

For the application herein, the signal of interest is the flow noise for different diameter towed arrays. The interference is the tow ship which at high speeds will be a dominant phenomenon. The reference for cancellation is a beam steered at the tow ship. Ideally, the reference beam should be formed using hydrophones other than those on which the flow noise measurements are being made. Then there are no common elements, there are no correlated components due to the flow noise in the reference, and an unbiased estimate of the flow noise results at the cancelled hydrophone output. It is precisely this approach which is to be used on the high speed trials (FY 1978).

For the initial sea test, at low towing speeds, the flow noise differences for the two array diameters could be measured directly because of the quiet tow ship. To artificially create a strong tow ship interference, the HX-90 source, Figures (29, 30) was towed as well, so that it and the tow ship both enter on the endfire beam of towed array, Figure 31. When the strong source is on, hydrophone outputs consist primarily of plane wave interference from the towed source. To demonstrate the cancellation at sea, the endfire beam was used as a reference and the interference components were removed from any other of the twenty pre-formed beams.

VI. HARDWARE EVALUATION

The HSTAS Program involved essentially three phases of evaluation:

1. In-plant/laboratory testing
2. Acoustic calibration
3. Sea Test

The first two are treated in this section, while the third is treated separately in section VII.

A. In Plant/Laboratory Testing

In order to verify that the system was operational, all the primary components shown on Figure 1 (including the tow cable) were assembled at Hughes in June of 1977 for system test and check-out. A representative list of the kinds of items that were checked follows:

1. Hydrophone polarity
2. Telemetry transmitter frequency vs. location
3. Telemetry carrier RF levels
4. Array power supply operation
5. Electrical continuity in the array
6. Hose module pressure test
7. Array telemetry can pressure test
8. Array module tension test
9. Nose-cone to tow cable tension test

10. Receiver to beamformer interface

11. Beamformer to MINIPRO interface

12. Beamformer beampattern verification

    (a) Shaded

    (b) Un-shaded

13. Beamformer CGA Operability

14. MINIPRO functioning (operability)

15. RF Tape Recorder Operability

16. RF Tape Recorder/Beamformer Interface

Representative data from the in-plant testing are shown in Figures 19 and 20. Figure 19 is a typical trace of electronic noise level vs. frequency at the output of a particular receiver channel. This latter curve is essentially the same as the original test data obtained when the equipment was first put to sea.

Figure 20 is a chart summarizing the following important data:

1. Receiver card location (receiver location)
2. Data Channel Number
3. Carrier Frequency (KHz)
4. Carrier Amplitude level (dbm)
5. Sensor location (F=FAM, ACC=Accelerometer, A.C.=Acoustic Control).

B. Acoustic Calibration

The entire array and telemetry receiver were taken to NRL at Leesburg, Florida and subjected to an acoustic calibration. This permits the determination of an overall transfer function from the "water" to the receiver output. The details of this calibration will be reported in the forthcoming MAR Inc. report documenting their participation in the HSTAS Program. Preliminary data are available in reference 5.

VII. SEA TEST

The High Speed Towed Array System (HSTAS) was sea tested aboard the R/V Harris (Trial 7H8) in Exuma Sound during the period 16 to 22 July 1977.

All the goals set forth in Section II of this report were met within the operational constraints of the R/V Harris (i.e., Top speed in the vicinity of 20 knots). The planning of the sea test is fully documented in reference 4.

For the sake of clarity, the discussion of the actual data will be divided into two parts:

A. Array Self Noise Data

B. MINIPRO - Adaptive Noise Canceller Data

A. Array Self Noise Data

Two types of array self noise data were acquired during the sea trial; channel level and beam output. As mentioned in Section II, Goals; the intent was to achieve a measure of relative self-noise performance between the FAM and Control Modules only.

Figures 22 through 26 show the relative performance (channel level) of the Control Modules (3") and the FAM (6") for speeds from 6 to 18 kts. It is clear from an inspection of these latter figures that the FAM was quieter at all speeds and frequencies. In particular, at the higher speeds (12 kts), the FAM is as much as

15 dB quieter at 100 Hz. Although the latter comparison is very satisfying in that it supports the theory set forth by Chase[1], there are still many unanswered questions that can only be resolved by further modeling, data analysis and experimentation. In particular, the influence of the telemetry cans and hydrophones as scattering centers in the control modules is difficult to assess at this time. Thus, further work is needed before any definitive conclusions concerning the validity of the theory (ref 1) about the affect of array diameter on self noise can be made.

Regarding self noise levels measured at the beamformer output, Figures 27 and 28 are two typical cases for 15 Kts. and 18 Kts. respectively. The solid line in each figure represents the single channel self noise in FAM averaged over all of the channels. The distance below this line to any particular beam at any frequency represents the beamformer gain. As might be expected the beamformer gain is higher for beams with MRA's in the second quadrant (090° to 180°) than in the first (000° to 090°) where radiated noise is entering the beam on the main lobe. Beamforming was done only with the 20 uniformly spaced channels in the FAM and therefore the control module channels were not involved at this point.

It is to be emphasized that from a systems point of view, only a beamformer output self noise level is of any significance. These latter curves underscore two important facts:

1. The beamformer was indeed operational at sea.

2. The contamination of the forward beams by ownship radiated noise indicates the need for a noise canceller if full azimuthal coverage is to be achieved at high speed.

B. MINIPRO-Adaptive Noise Canceller Data

The results taken at sea using the MINIPRO Adaptive Noise Canceller (with subsequently identified programming errors) are shown in Figures 32 (Broadband Source Spectrum) and 33 (Narrowband Source Spectrum). The source spectra were obtained by driving the HX-90 with a random noise generator shaped by a one third octave filter set for the broadband case and an oscillator plus the random noise generator for the narrowband case.

Figures 32 and 33 each contain three traces which are the outputs of the reference beam (pointed at the HX-90), the beam of interest, and the beam of interest with the interference from the reference beam subtracted from it. This last curve is labeled "PIC'D" in the figures. In the narrowband case the beam of interest was the broadside beam. In the broadband case beam 6 at bearing 060° was used. The difference in level between the reference beam and the other beam outputs is due to the sidelobe rejection of the HX-90 by the beams of interest. The difference in level between the broadside beam (or beam 6) "PIC'D" and "UN-PIC'D" represents the cancellation provided by the adaptive filter. Figure 32 shows broadband cancellation of 6 to 15 dB depending on frequency while Figure 33 shows 18 dB of cancellation (at the tonal peak) for the narrowband case.

Hydrophone data was recorded during the sea test and used for further laboratory testing afterward. Several hardware and software errors were identified in Minipro. These problems were corrected, and the data in Figures 32 and 33 were re-run with the canceller operating correctly. The results, shown in Figures 34 and 35 show the increase in cancellation capability. Comparison of Figures 34 with 32 shows an increased low frequency cancellation (below 100 Hz), and reduction of the interference in the mid-band region down to the noise floor. The broadband source was cancelled by 23 dB in the center of the band.

Comparison of Figure 35 with 33 demonstrates the extent of the improvement in narrowband cancellation as a result of the corrections to Minipro. The tonal interference at 550 Hz is reduced by approximately 25 dB.

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. The goals of the HSTAS Program for 1977 were met completely within the operational constraints of the R/V Harris. Specifically:

1. An HSTAS was successfully designed, fabricated and tested at sea.

2. Self noise data was acquired for two different diameter modules in the same array. The results support the theory (6" quieter than 3") but need to be studied more extensively as well as repeated before any generalizations can be made.

3. An adaptive noise canceller was successfully demonstrated at sea, and should be an integral component of any high speed, tow-ship noise limited system.

B. The HSTAS system has been demonstrated to be ready for tests at speeds in the 35 knot range.

For the next phase of testing, the adaptive noise canceller should be applied at the hydrophone (channel level) as well as on beam outputs to permit direct observation of the flow noise at the hydrophone level at high speeds. To demonstrate the tactical utility of the system, a test involving a second (source) ship at various combinations of range, speed and bearing could assess the detection capability at high speeds.

IX. FIGURES

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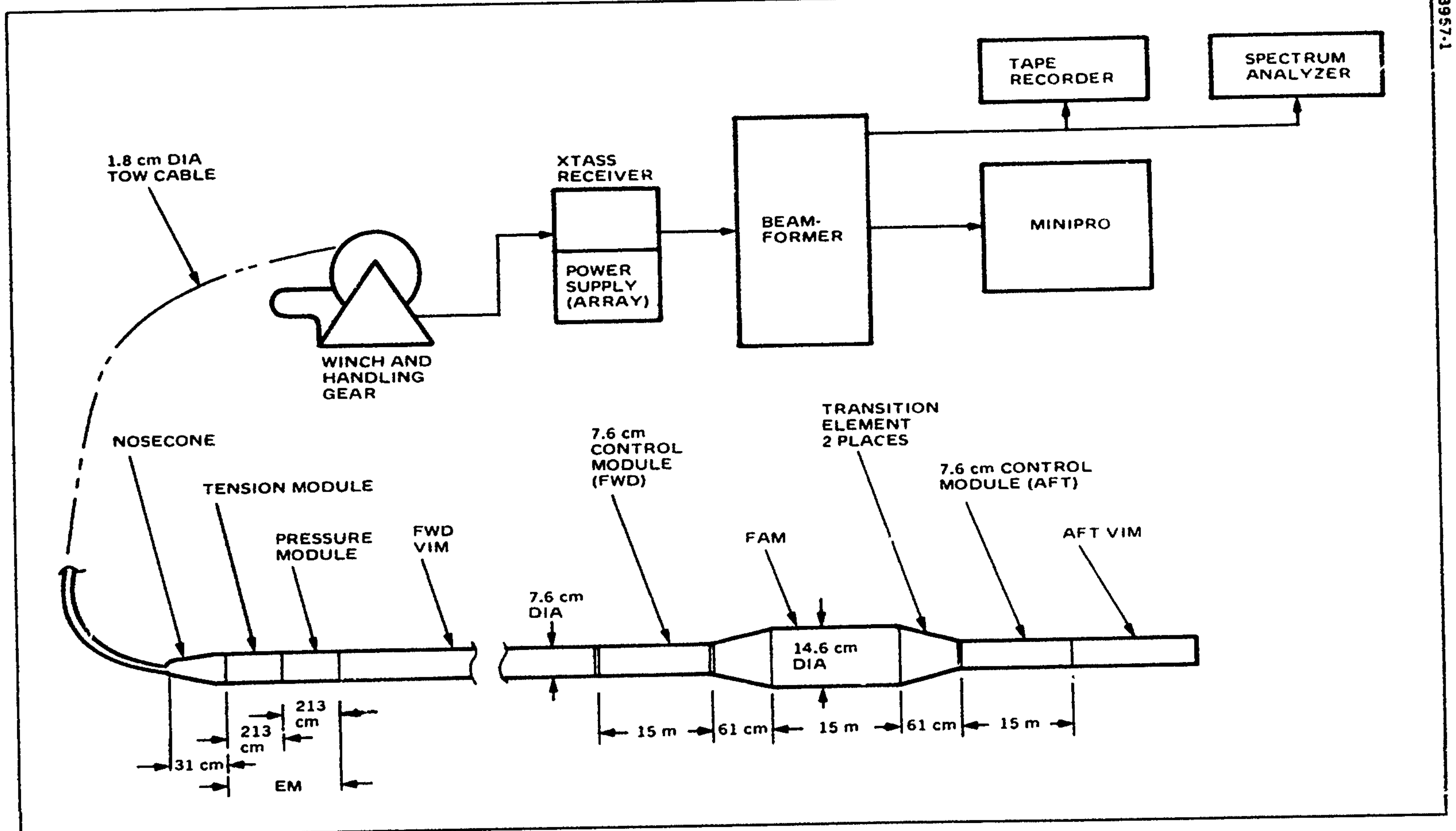


Figure 1. ONR High-Speed Towed Array System (HSTAS)

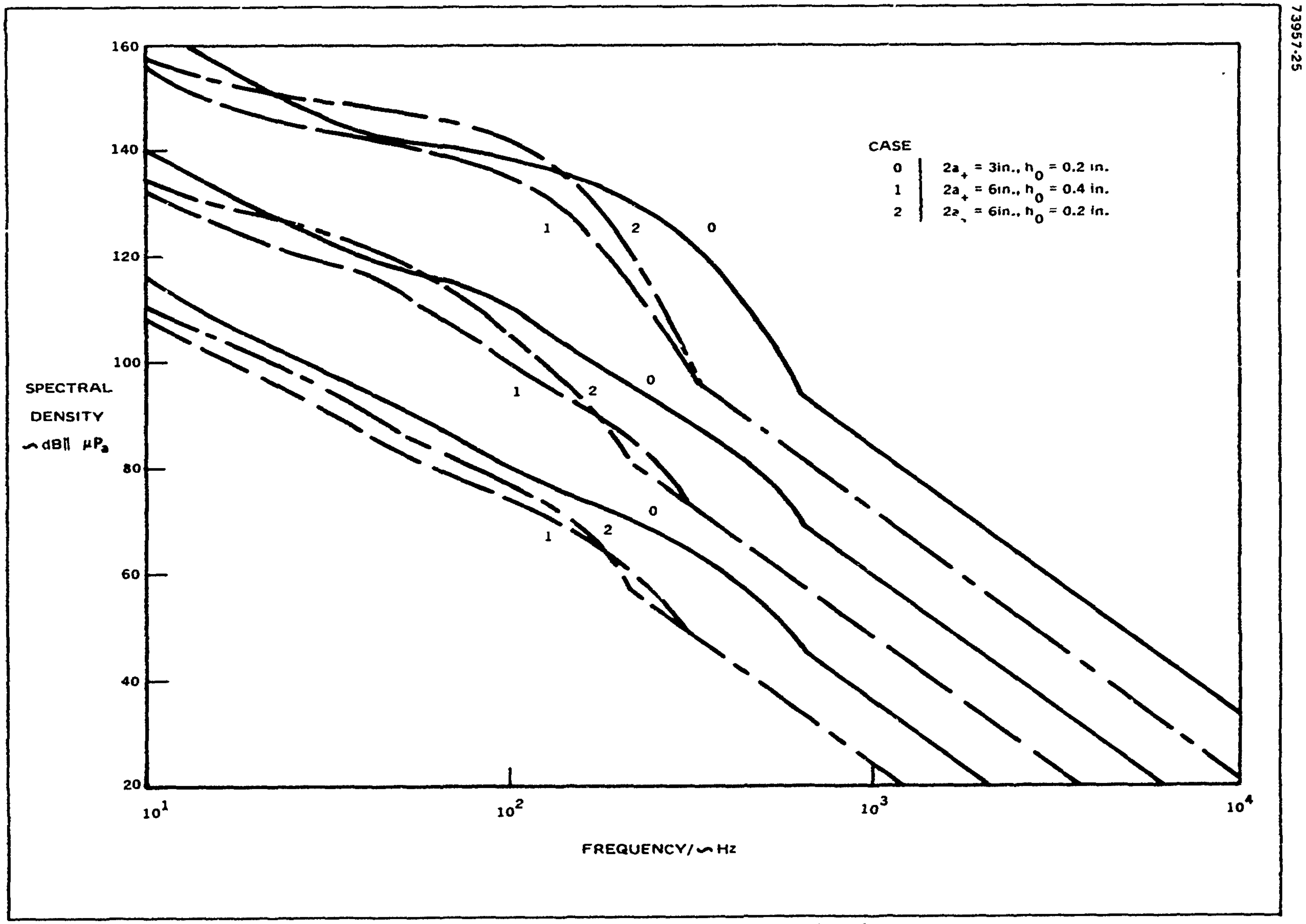


Figure 2. Computed Spectral Density of Total Direct Turbulence-induced Pressure on Axis at 15, 30, and 60 kt for Hoses of Two Different Diameters with Hosewall Thickness Unchanged or Changed Proportionately. Labels refer to case numbers.

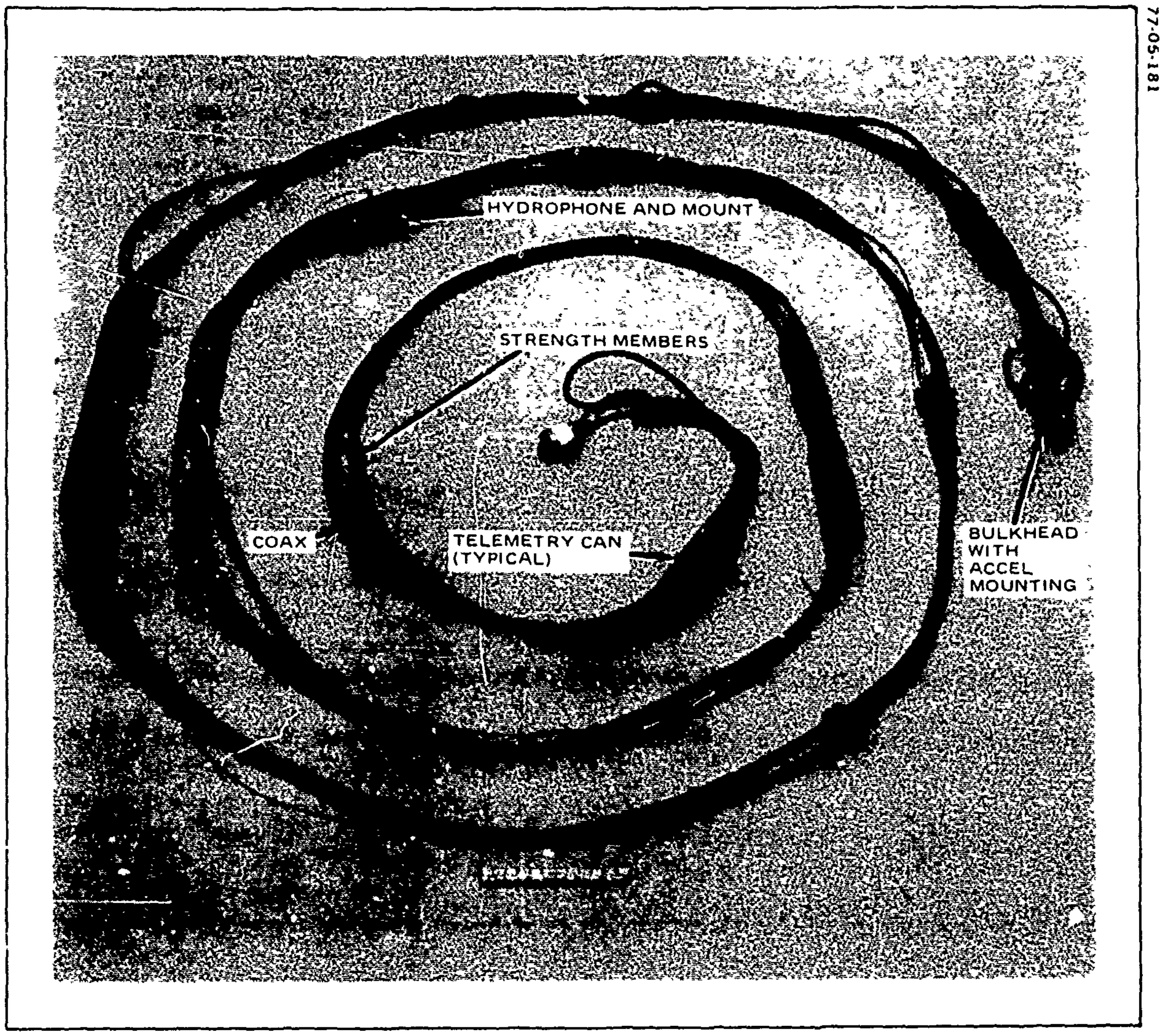


Figure 3. Control Module Interior

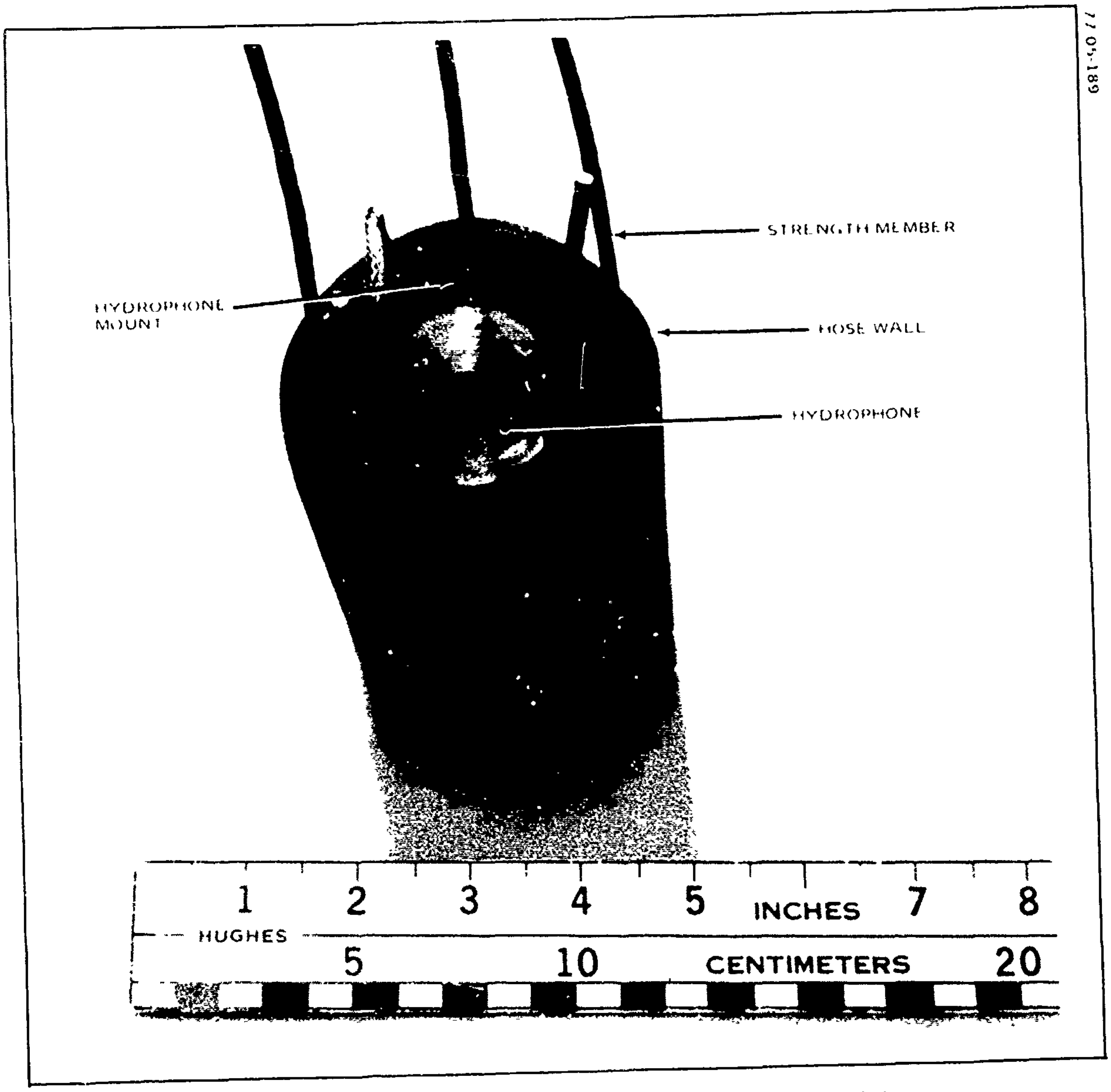
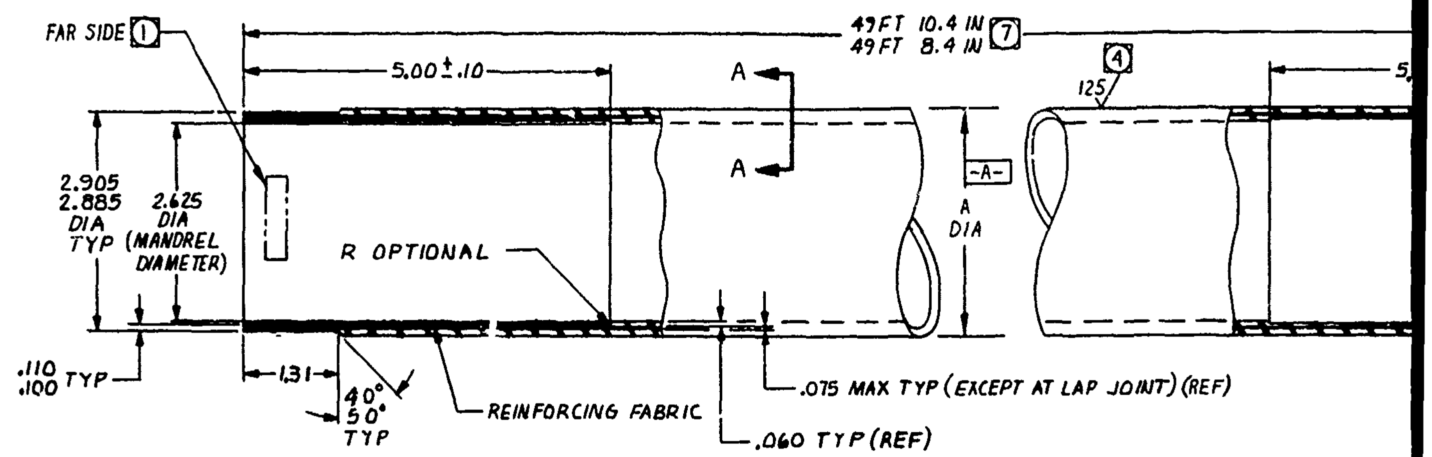


Figure 4. Hydrophone Installation – Control Module



NOTES - UNLESS OTHERWISE SPECIFIED

1. MARK 05869-710-1175-017 PER MIL-M-13231 OF II, USING MIL-I-43553 INK LOCATED APPROXIMATELY WHERE SHOWN.

2. THE ACOUSTIC MODULE (AM) HOUSING (HOSE) SHALL BE CONSTRUCTED FROM ELASTOMERIC MATERIALS BUTYL AND NITRILE BUTADIENE RUBBER AND REINFORCING FABRICS AS SHOWN IN SECTION A-A. THE HARDNESS OF THE BUTYL LAYER SHALL BE 60 ± 5 SHORE A. THE NITRILE-BUTADIENE RUBBER SHALL BE OF A TYPE WHICH BEST RESISTS PERMEATION OF THE MINERAL SPIRITS THROUGH THE AM HOUSING TUBE WALL. THE REINFORCING FABRIC MUST BE HEAT SET PRESTRETCHED OR EQUIVALENT TO ELIMINATE ANY BAGGING OF THE HOSE AFTER LONG-TERM USAGE. ALL MATERIALS USED SHALL BE OF TYPE AND QUALITY WHICH WILL SATISFY THE REQUIREMENTS OF THIS SPECIFICATION. THE SULFUR CONTENT OF THE NITRILE-BUTADIENE RUBBER SHALL BE HELD TO AN ABSOLUTE MINIMUM CONSISTENT WITH FABRICATION REQUIREMENTS. THE LAYERS OF RUBBER AND FABRIC SHALL SHOW NO EVIDENCE OF PLY SEPARATION WHEN FOLDED FLAT OR ROLLED IN THE UNFILLED CONDITION.

3. <u>CIRCUMFERENTIAL AND LONGITUDINAL STIFFNESS - DESIGN GOAL</u>. THE AM HOUSING SHALL BE A RIGHT ANGLE (CIRCUMFERENTIAL AND LONGITUDINAL) 2-PLY CONSTRUCTION, AND THE STIFFNESS CONTRIBUTION IN EACH PRINCIPAL DIRECTION IS INTENDED TO BE OBTAINED SOLELY BY THE FABRIC PLY (AND RUBBER) IN THAT DIRECTION.

4. <u>SURFACE FINISH</u>. THE EXTERNAL SURFACE FINISH OF THE AM HOUSING SHALL BE FREE OF FLAWS AND IMPERFECTIONS. THE SURFACE SHALL BE UNIFORMLY SMOOTH AS ACCOMPLISHED BY GRINDING OR EQUIVALENT TO THAT PRODUCED BY A STRAIGHT WRAP FINE WEAVE FABRIC. SURFACE IRREGULARITIES OVER A DEPTH OF .015 SHALL BE BLENDED INTO THE ADJACENT SURFACE.

5. <u>DIMENSIONAL STABILITY - DESIGN GOAL</u>. THE HOSE, WHEN FILLED WITH THE DIELECTRIC FLUID, SHALL MAINTAIN ITS DIAMETRICAL DIMENSIONS UNDER THE FOLLOWING CONDITIONS (SEE NOTES a, b, c).

   (1) AT ROOM TEMPERATURE, DIELECTRIC FLUID PRESSURE 30 ± 2 PSI.

   (2) AT ROOM TEMPERATURE, FLUID PRESSURE 2 PSI MINIMUM.

   (3) AFTER 14 DAYS AT 125°F ± 5°F, IMMERSED IN OCEAN WATER, DIELECTRIC FLUID PRESSURE 30 ± 2 PSI. REPEAT DIMENSIONAL AND VISUAL INSPECTIONS UNDER CONDITIONS (1) AND (2).

   <u>NOTES</u>: (a) FLUID TO BE REPLENISHED AS NECESSARY TO MAINTAIN TEST PRESSURES.

   (b) THE DIELECTRIC FLUID SHALL BE 030 760562.

   (c) OCEAN WATER SHALL BE IN ACCORDANCE WITH ASTM D1141.

6. NO SURFACE IRREGULARITIES WILL BE GENERATED WHEN THE ASSEMBLY IS SUBJECTED TO A TENSILE LOAD OF 400 LBS.

7. DIMENSIONS APPLY WITH ASSEMBLY SUBJECTED TO A 150 LB. TENSILE LOAD OF A MINIMUM OF TEN MINUTES. THIS MEASUREMENT SHALL BE MADE 30 MINUTES ± 5 MINUTES AFTER REMOVING THE LOAD OF NOTE 6 (400 LBS). TO REDUCE THE EFFECT OF FRICTION BETWEEN HOSE AND FLOOR OR BENCH THE HOSE SHALL BE LIFTED IN INCREMENTS OF 5 TO 6 FEET ONE INCREMENT AT A TIME ALONG ITS LENGTH DURING ELONGATION (LOADING) AND CONTRACTION (UNLOADING).

8. <u>ENVIRONMENTAL</u>. THE AM HOUSING SHALL BE DESIGNED TO MEET THE FOLLOWING TEMPERATURE CONDITIONS WITH NO SEPARATION BETWEEN PLIES, LEAKAGE, BLISTERING, OR OTHER DAMAGE DURING AND AFTER THE TESTS:

OPERATIONAL	-2°C TO +40°C
STORAGE	-62°C TO +75°C

FURTHER, THE AM HOUSING SHALL BE FUNGUS RESISTANT PER MIL-STD-810, AND THE BUTYL LAYER OF THE HOUSING SHALL PROVIDE OZONE RESISTANCE PER MIL-STD-417.

9. <u>ELECTRICAL PROPERTIES - DESIGN GOAL</u>. AFTER THE HOSE HAS BEEN FILLED WITH THE DIELECTRIC FLUID AND IMMERSED IN OCEAN WATER FOR 14 DAYS AT 125 ± 5°F, IT SHALL HAVE THE FOLLOWING MINIMUM RESISTIVITY VALUES PER ASTM D257:

   (1) THROUGH THE WALL THICKNESS: 10^6 OHMS/SQ. IN

   (2) ALONG THE INNER NITRILE LINER: 10^5 OHMS/IN.

10. <u>COLOR</u>. THE COLOR OF THE AM HOUSING SHALL BE NON-REFLECTIVE BLACK.

11. <u>ABRASION RESISTANCE - DESIGN GOAL</u>. THE AM HOUSING SHALL BE CAPABLE OF WITHSTANDING THE ABRASIVE EFFECTS PRODUCED DURING HANDLING ON SHIPBOARD, DEPOTS, AND SHOP FLOORS.

12. <u>PRESSURE</u>. THE AM HOUSING SHALL WITHSTAND A PRESSURE OF 50 PSIG FOR 1 HOUR WITHOUT LEAKAGE, PLY SEPARATION, BLISTERING OR OTHER PERCEPTABLE DAMAGE. THE DIAMETER INCREASE RESULTING FROM AN INTERNAL PRESSURE INCREASE FROM 0 TO 30 PSIG SHALL BE LESS THAN 2 PERCENT.

13. <u>ELONGATION</u>. RELATIVE ELONGATION WITH 125 LBS LONGITUDINAL LOAD SHALL BE LESS THAN 1.0 INCH. RESIDUAL ELONGATION FOLLOWING FIRST APPLICATION OF LONGITUDINAL LOAD SHALL BE LESS THAN 0.4 PERCENT.

14. THE INSPECTION TESTS TO BE PERFORMED ON EACH UNIT TO DETERMINE ACCEPTANCE OR REJECTION WILL BE AS FOLLOWS AND IN THE ORDER SHOWN:

   (1) VISUAL AND DIMENSIONAL AT ATMOSPHERIC PRESSURE.

   (2) VISUAL INSPECTION AT 400 LBS. TENSION LOAD. (SURFACE IRREGULARITIES).

   (3) DIMENSIONAL INSPECTION AT 150 LBS. TENSION LOAD. (LONGITUDINAL).

   (4) VISUAL AND DIMENSIONAL INSPECTION AT 30 PSI INTERNAL PRESSURE. (DIAMETRICAL).
   THIS WILL INCLUDE THE MEASUREMENT OF DEVIATIONS IN SURFACE REGULARITY WHERE INDICATED.

   (5) PRESSURE

   (6) ELONGATION.

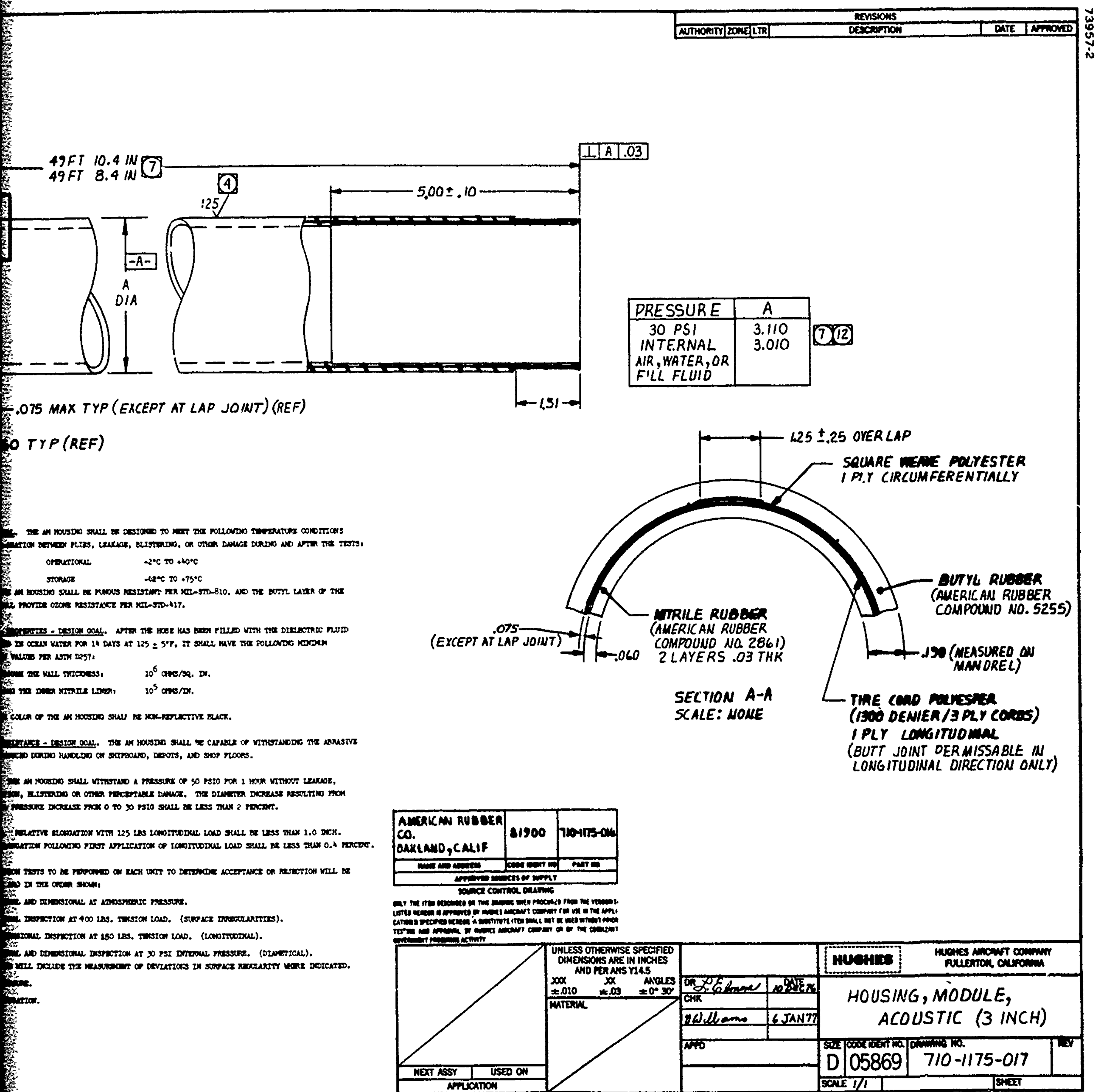


Figure 5. Control Module Hose – Engineering Drawing

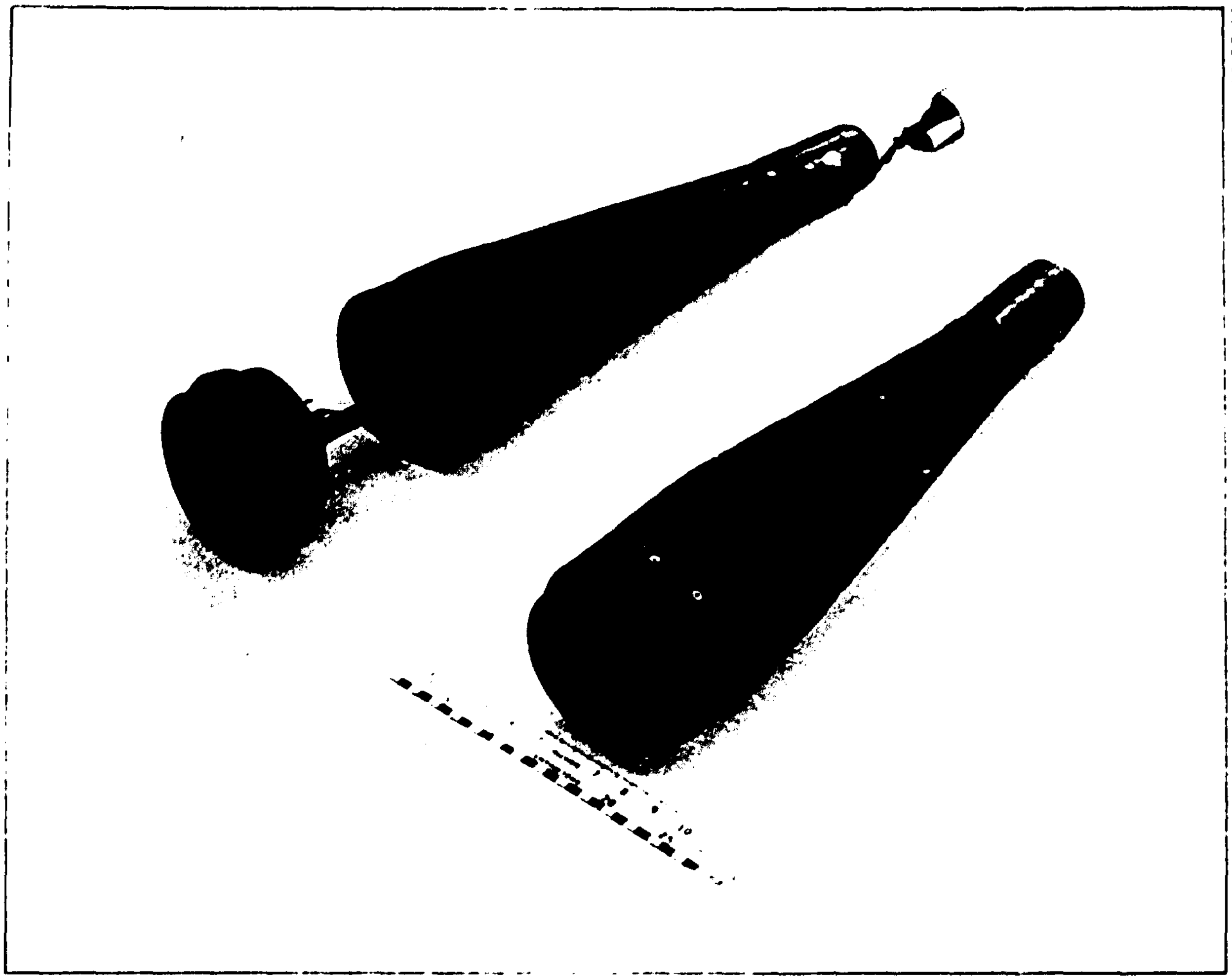
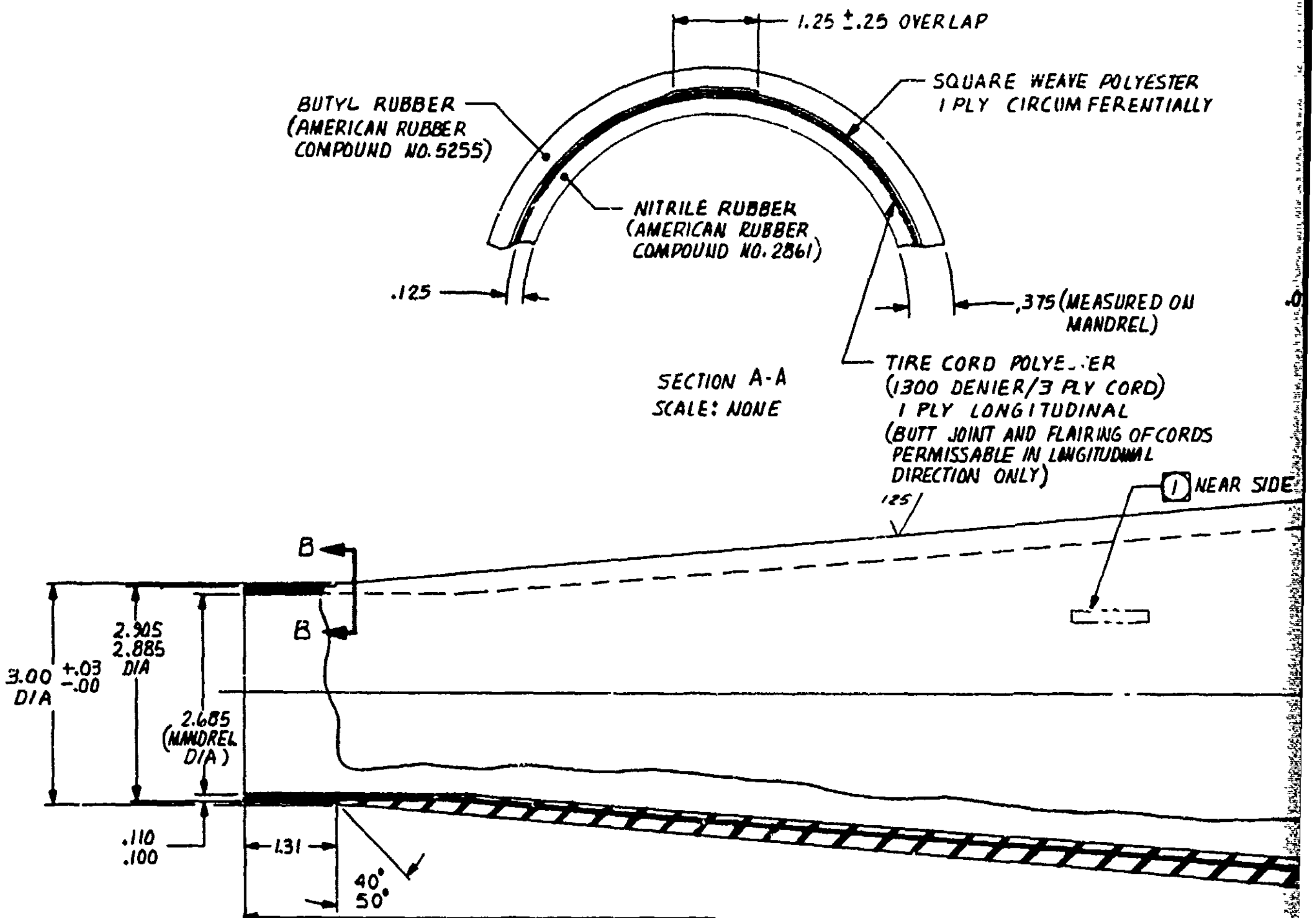


Figure 6. Fore and Aft Transition Elements



NOTES - UNLESS OTHERWISE SPECIFIED

1. MARK 05869-710-1175-018 PER MIL-M-13231 OF II, USING MIL-I-43553 INK LOCATED APPROXIMATELY WHERE SHOWN.

2. TRANSITION MODULE (TM) HOUSING (HOSE) SHALL BE CONSTRUCTED FROM ELASTOMERIC MATERIALS BUTYL AND NITRILE BUTADIENE RUBBER AND REINFORCING FABRICS AS SHOWN IN SECTION A-A & B-B. HARDNESS OF THE BUTYL LAYER SHALL BE 60 ± 5 SHORE A. THE NITRILE-BUTADIENE RUBBER SHALL BE OF A TYPE WHICH BEST RESISTS PERMEATION OF THE MINERAL SPIRITS THROUGH THE AN HOUSING TUBE WALL. THE REINFORCING FABRIC MUST BE HEAT SET PRESTRETCHED OR EQUIVALENT TO ELIMINATE ANY BAGGING OF THE HOSE AFTER LONG-TERM USAGE. ALL MATERIALS USED SHALL BE OF TYPE AND QUALITY WHICH WILL SATISFY THE REQUIREMENTS OF THIS SPECIFICATION. THE SULFUR CONTENT OF THE NITRILE-BUTADIENE RUBBER SHALL BE HELD TO AN ABSOLUTE MINIMUM CONSISTENT WITH FABRICATION REQUIREMENTS. THE LAYERS OF RUBBER AND FABRIC SHALL SHOW NO EVIDENCE OF PLY SEPARATION.

3. A METAL-TO-HOSE BOND SHALL BE PROVIDED WITH A SEPARATION STRENGTH WHICH WILL EQUAL OR EXCEED THAT OF THE HOSE AND SHOW NO DELETERIOUS EFFECTS WHEN SUBJECTED TO THE SAME ENVIRONMENTAL CONDITIONS AS THE HOSE.

4. CIRCUMFERENTIAL AND LONGITUDINAL STIFFNESS - DESIGN GOAL. THE TRANSITION HOSE SHALL BE 2-PLY CONSTRUCTION AND THE STIFFNESS CONTRIBUTION IN EACH PRINCIPAL DIRECTION IS INTENDED TO BE OBTAINED SOLELY BY THE FABRIC PLY (AND RUBBER) IN THAT DIRECTION. THE FABRIC PLY SHALL BE LAYED IN A MANNER THAT WILL PREVENT THE TRANSITION HOSE FROM TORQUING UNDER A TENSION LOAD OF 800 LBS. EACH PLY SHALL BE OVERLAPED 180° APART. THE REINFORCING FABRIC AND CORD ARRANGEMENTS SHOWN ARE OPTIONAL, AND OTHER MATERIALS AND ARRANGEMENTS THAT WILL FULFILL THE PERFORMANCE REQUIREMENTS OF THIS SPECIFICATION MAY BE USED ONLY UPON WRITTEN APPROVAL BY HUGHES AIRCRAFT CO.

5. SURFACE FINISH. THE EXTERNAL SURFACE FINISH OF THE TM HOUSING SHALL BE FREE OF FLAWS AND IMPERFECTIONS AND SHALL BE FINISHED FLUSH WITH ITEM 1 WITHIN .005. THE SURFACE SHALL BE UNIFORMLY SMOOTH AS ACCOMPLISHED BY GRINDING OR EQUIVALENT TO THAT PRODUCED BY A STRAIGHT WRAP FINE WEAVE FABRIC. SURFACE IRREGULARITIES OVER A DEPTH OF .015 SHALL BE BLENDED INTO THE ADJACENT SURFACE.

6. DIMENSIONAL STABILITY - DESIGN GOAL. THE ASSY, WHEN FILLED WITH THE DIELECTRIC FLUID, SHALL MAINTAIN ITS DIAMETRICAL DIMENSIONS UNDER THE FOLLOWING CONDITIONS (SEE NOTES a, b, c).

(1) AT ROOM TEMPERATURE, DIELECTRIC FLUID PRESSURE 30 ± 2 PSI.

(2) AT ROOM TEMPERATURE, FLUID PRESSURE 2 PSI MINIMUM.

(3) AFTER 14 [illegible] AT 125°F ± 5°F, IMMERSED IN OCEAN WATER, DIELECTRIC FLUID PRESSURE 30 ± 2 PSI. REPEAT DIMENSIONAL AND VISUAL INSPECTIONS UNDER CONDITIONS (1) AND (2).

NOTES:
(a) FLUID TO BE REPLENISHED AS NECESSARY TO MAINTAIN TEST PRESSURES.
(b) THE DIELECTRIC FLUID SHALL BE GSO 760562.
(c) OCEAN WATER SHALL BE IN ACCORDANCE WITH ASTM D1141.

7. NO SURFACE IRREGULARITIES WILL BE GENERATED WHEN THE ASSEMBLY IS SUBJECTED TO A TENSILE LOAD OF 400 LBS. FOR A PERIOD OF 10 MINUTES.

8. DIMENSIONS APPLY WITH ASSEMBLY SUBJECTED TO A 150 LB. TENSILE LOAD FOR A MINIMUM OF TEN MINUTES. THIS MEASUREMENT SHALL BE MADE 30 MINUTES ± 5 MINUTES AFTER REMOVING THE LOAD OF NOTE 7 (400 LBS.).

9. ENVIRONMENTAL. THE TM HOUSING SHALL BE DESIGNED TO MEET THE FOLLOWING TEMPERATURE CONDITIONS WITH NO SEPARATION BETWEEN PLIES, LEAKAGE, BLISTERING, OR OTHER DAMAGE DURING AND AFTER THE TESTS:

OPERATIONAL	−2°C TO +40°C
STORAGE	−62°C TO +75°C

FURTHER, THE TM HOUSING SHALL BE FUNGUS RESISTANT PER MIL-STD-810, AND THE BUTYL LAYER OF THE HOUSING SHALL PROVIDE OZONE RESISTANCE PER MIL-STD-417.

NOTES CONTINUED ON SHEET 2

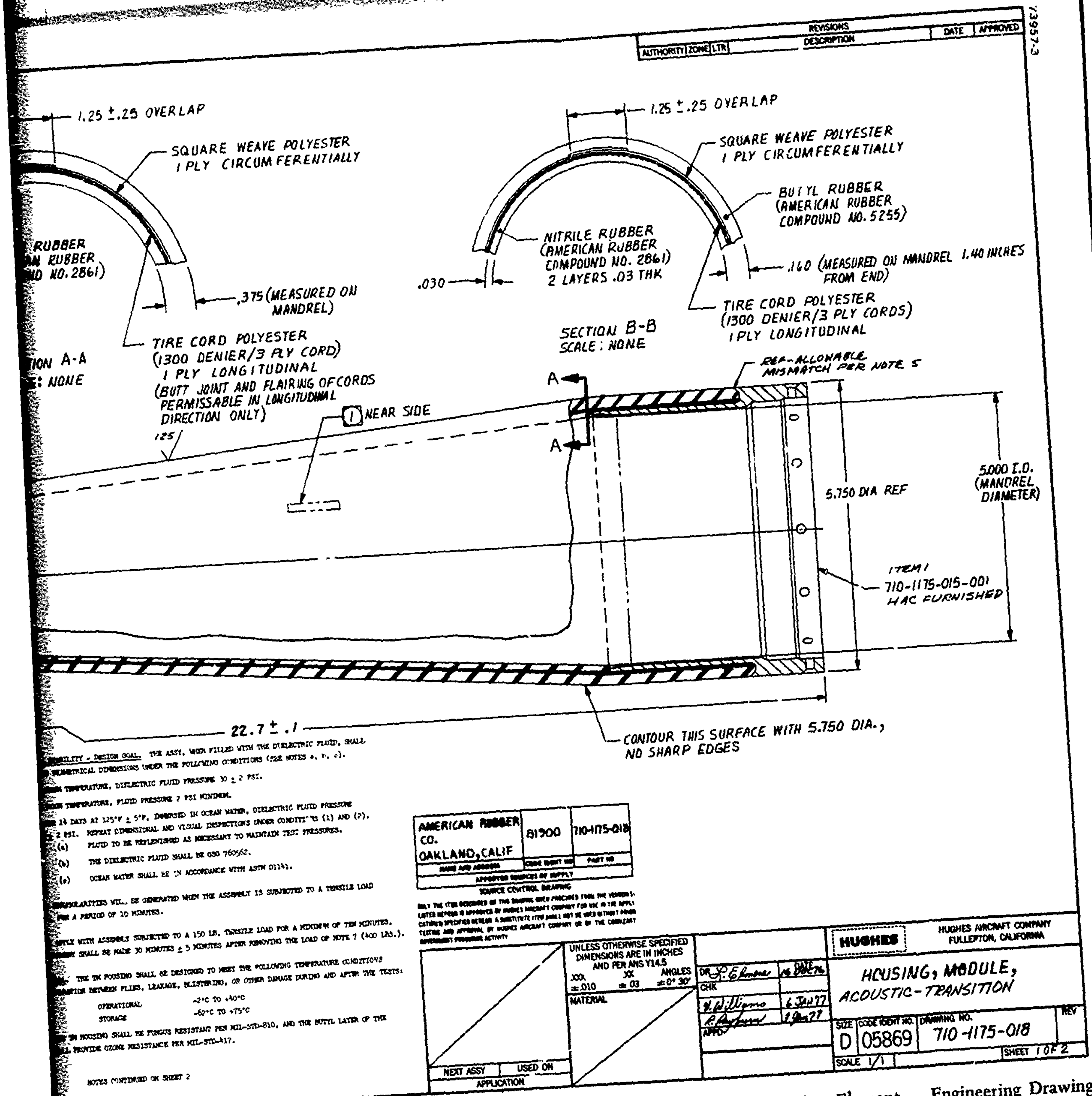


Figure 7. Transition Element – Engineering Drawing

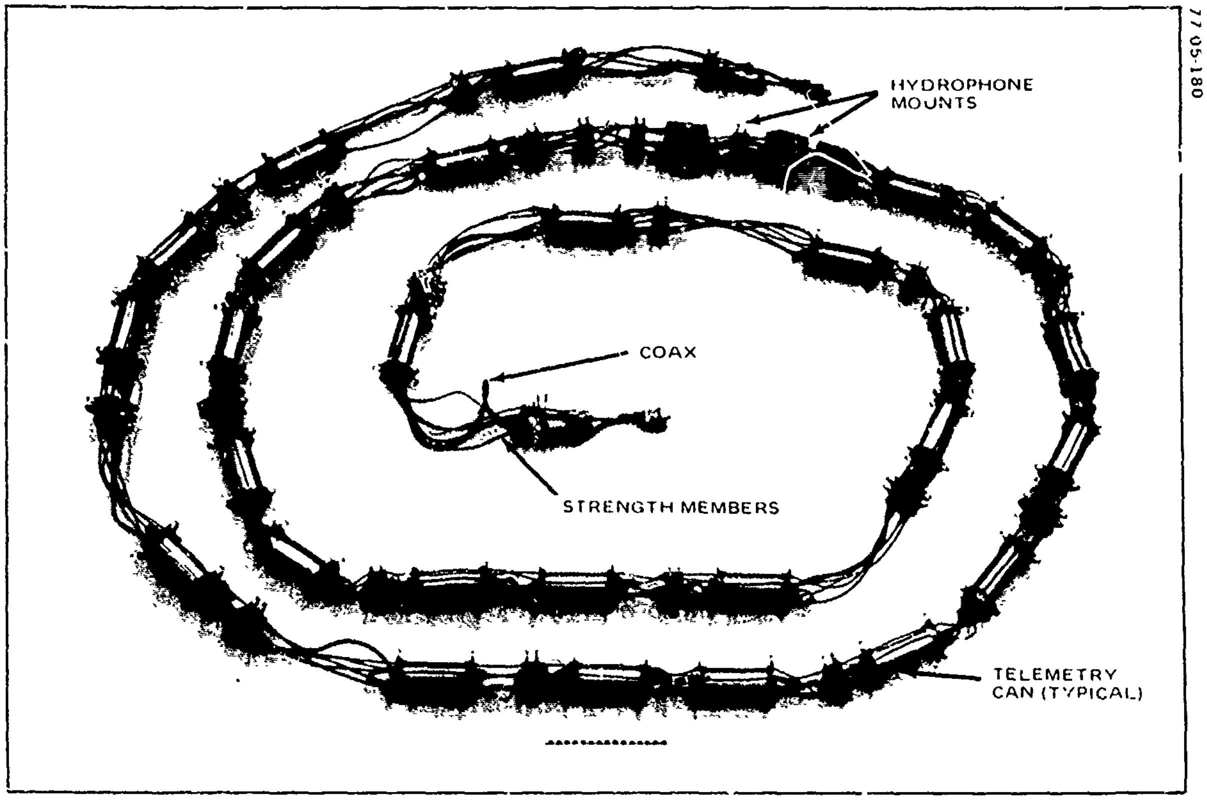


Figure 8. FAM Interior

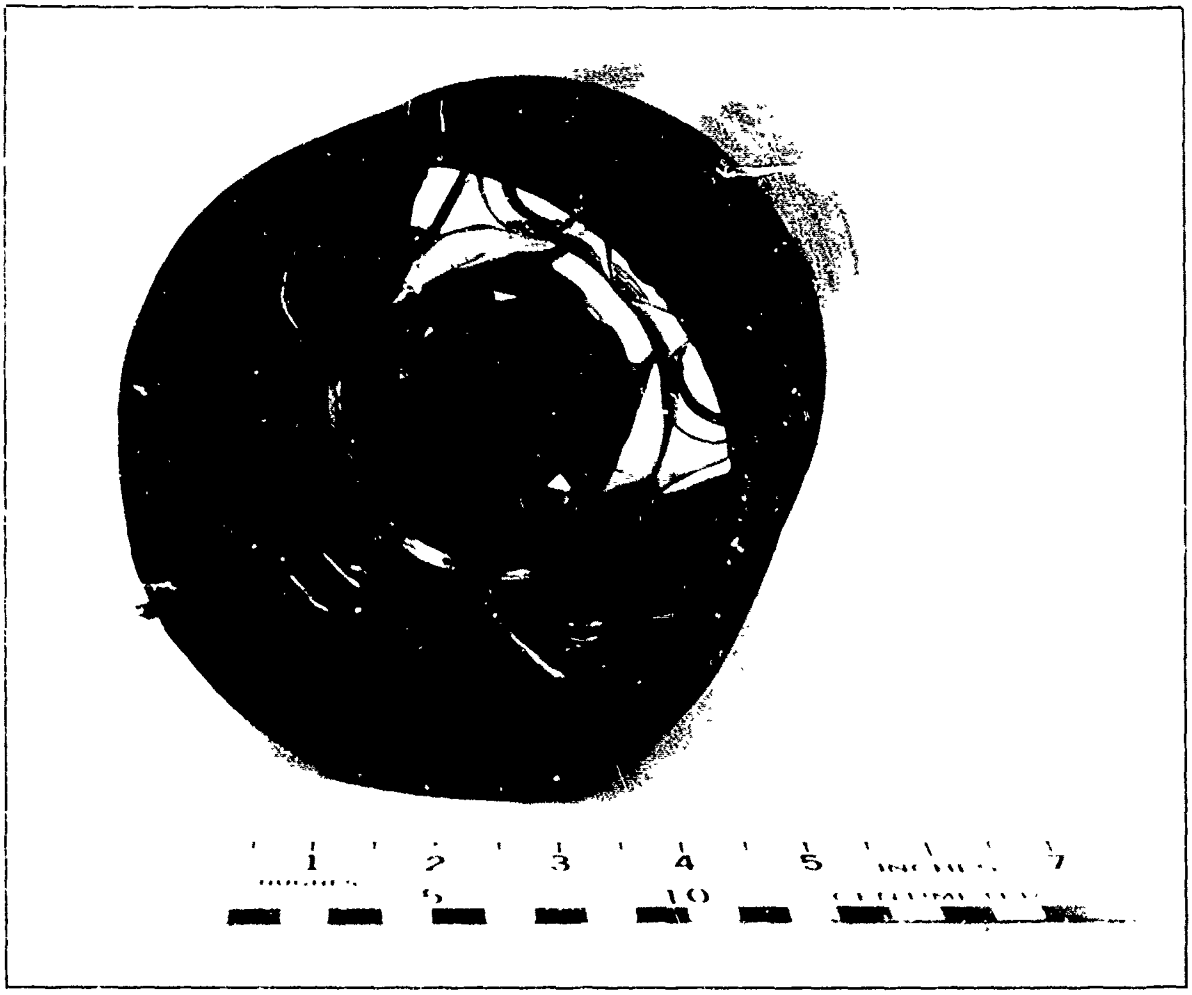


Figure 9. Hydrophone Mounting Scheme - FAM

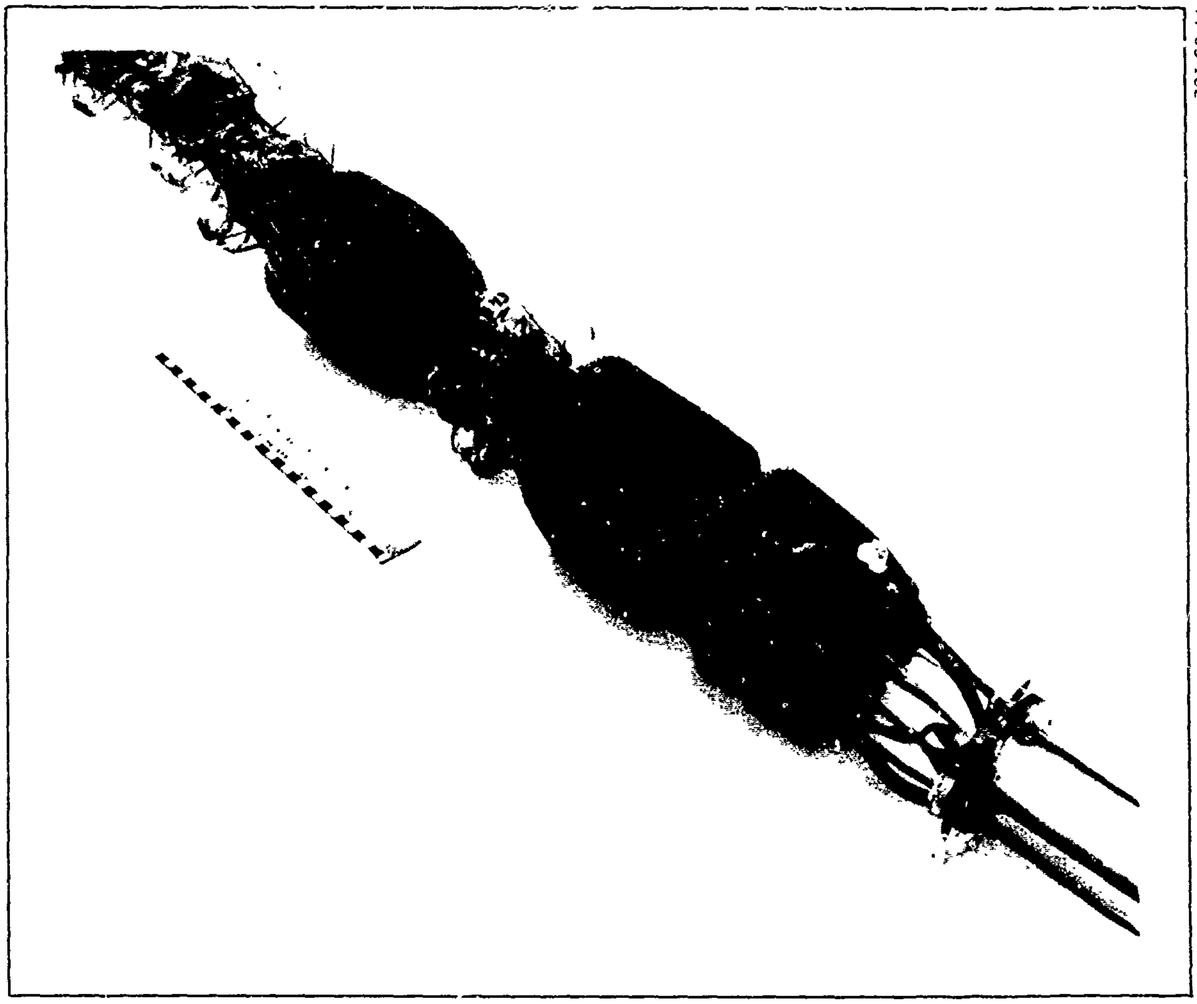


Figure 10. Hydrophone Mount Comparison - FAM

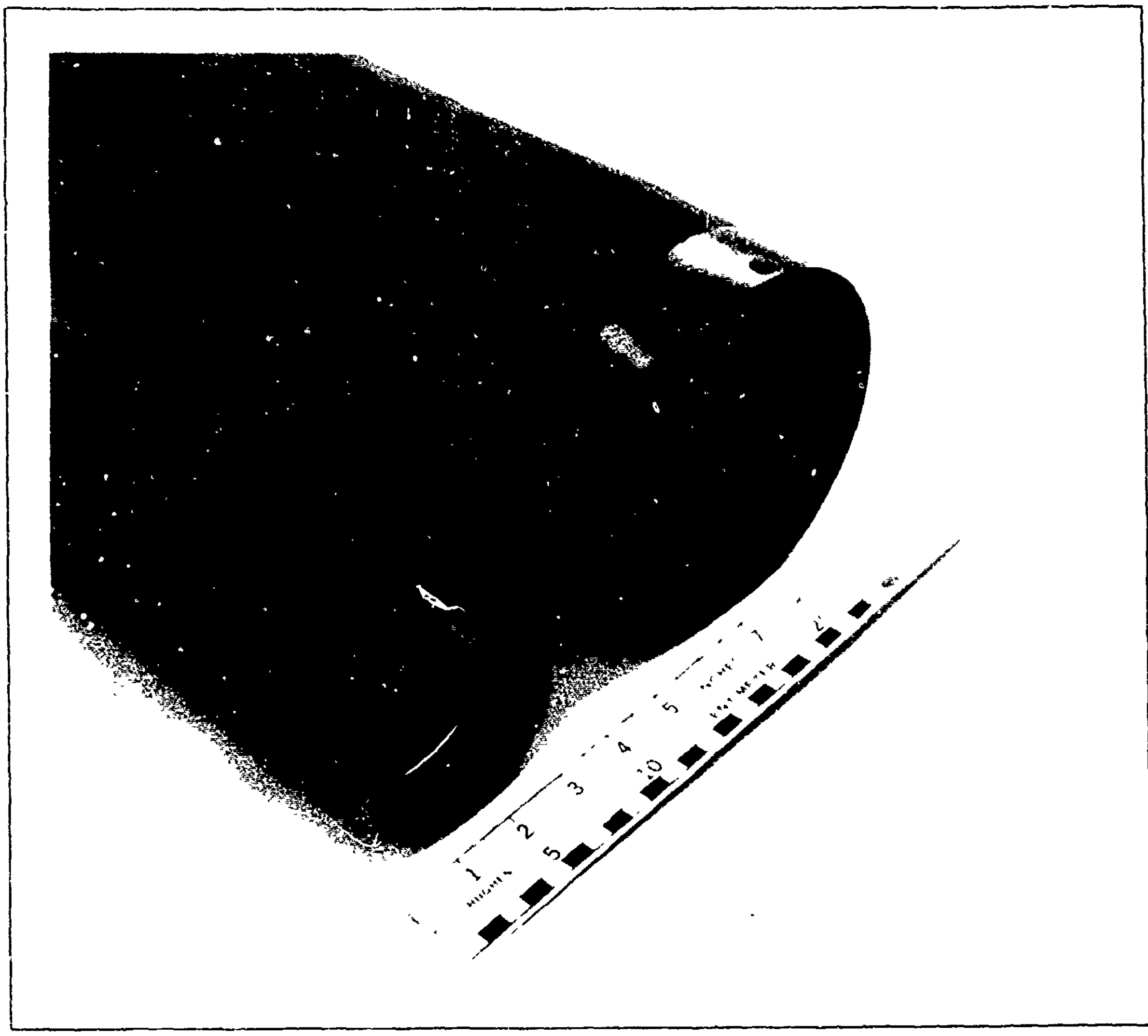


Figure 11 EAM and Control Module Hoses

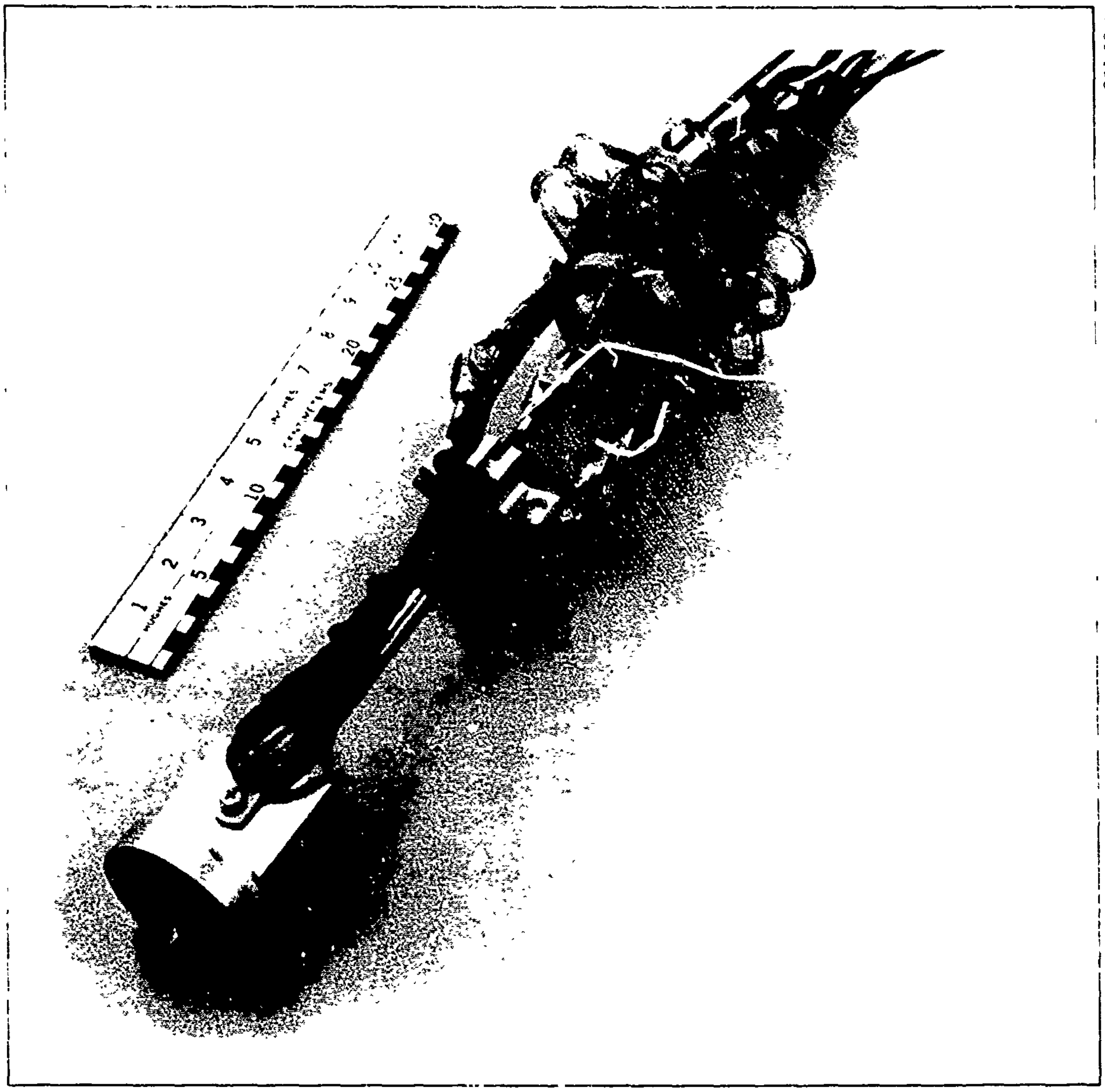
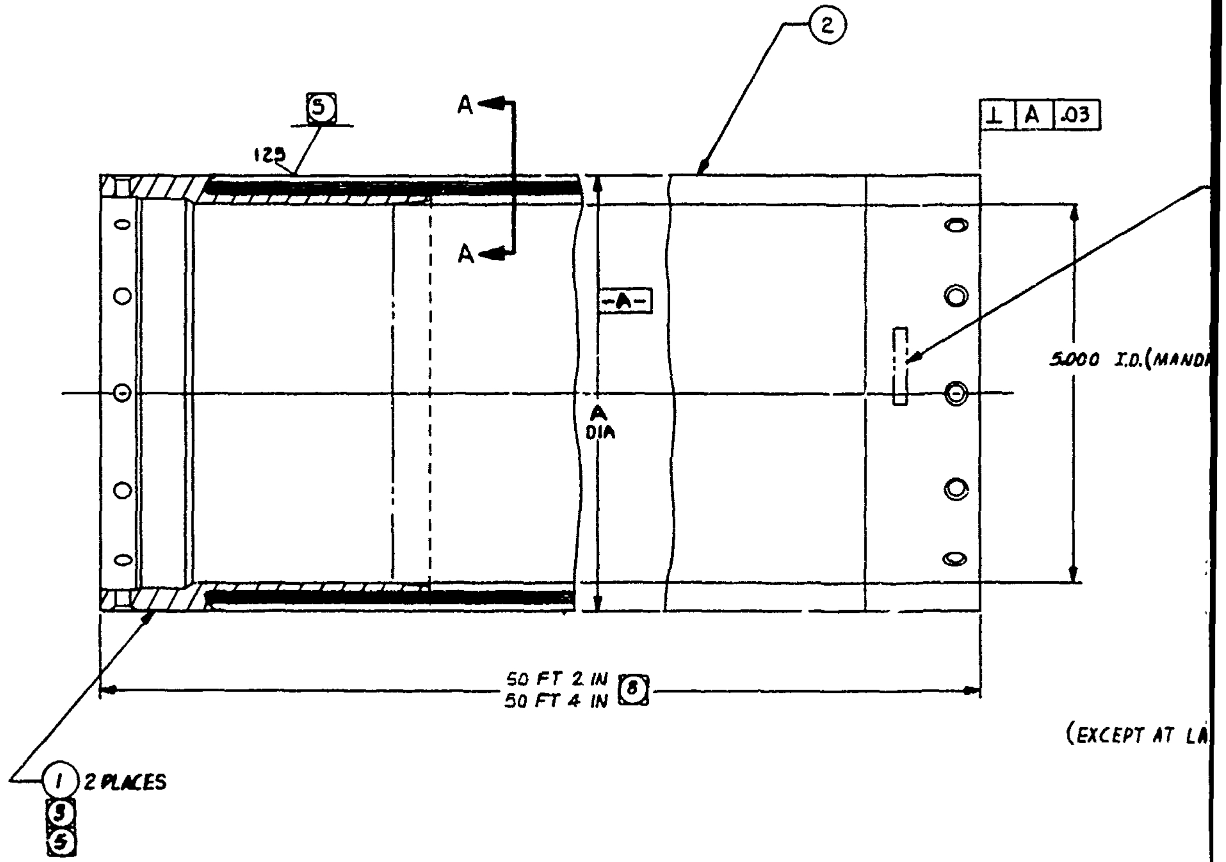


Figure 12. FAM Constructional Details



NOTES - UNLESS OTHERWISE SPECIFIED

1 MARK 05869-710-1175-015 PER MIL-M-13231 GP II, USING MIL-I-43553 INK LOCATED APPROXIMATELY WHERE SHOWN.

2. THE ACOUSTIC MODULE (AM) HOUSING (HOSE) SHALL BE CONSTRUCTED FROM ELASTOMERIC MATERIALS BUTYL AND NITRILE BUTADIENE RUBBER AND REINFORCING FABRICS AS SHOWN IN SECTION A-A. THE HARDNESS OF THE BUTYL LAYER SHALL BE 60 ± 5 SHORE A. THE NITRILE-BUTADIENE RUBBER SHALL BE OF A TYPE WHICH BEST RESISTS PERMEATION OF THE MINERAL SPIRITS THROUGH THE AM HOUSING TUBE WALL. THE REINFORCING FABRIC MUST BE HEAT SET PRESTRETCHED OR EQUIVALENT TO ELIMINATE ANY BAGGING OF THE HOSE AFTER LONG-TERM USAGE. ALL MATERIALS USED SHALL BE OF TYPE AND QUALITY WHICH WILL SATISFY THE REQUIREMENTS OF THIS SPECIFICATION. THE SULFUR CONTENT OF THE NITRILE-BUTADIENE RUBBER SHALL BE HELD TO AN ABSOLUTE MINIMUM CONSISTENT WITH FABRICATION REQUIREMENTS. THE LAYERS OF RUBBER AND FABRIC SHALL SHOW NO EVIDENCE OF DELAMINATION OR PLY SEPARATION WHEN FOLDED FLAT OR ROLLED IN THE UNFILLED CONDITION.

3 A METAL-TO-HOSE BOND SHALL BE PROVIDED WITH A SEPARATION STRENGTH WHICH WILL EQUAL OR EXCEED THAT OF THE HOSE AND SHOW NO DELETERIOUS EFFECTS WHEN SUBJECTED TO THE SAME ENVIRONMENTAL CONDITIONS AS THE HOSE.

4. <u>CIRCUMFERENTIAL AND LONGITUDINAL STIFFNESS - DESIGN GOAL</u>. THE AM HOUSING SHALL BE A RIGHT ANGLE (CIRCUMFERENTIAL AND LONGITUDINAL) 4-PLY CONSTRUCTION, AND THE STIFFNESS CONTRIBUTION IN EACH PRINCIPAL DIRECTION IS INTENDED TO BE OBTAINED SOLELY BY THE FABRIC PLY (AND RUBBER) IN THAT DIRECTION.

5 <u>SURFACE FINISH</u>. THE EXTERNAL SURFACE FINISH OF THE AM HOUSING SHALL BE FREE OF FLAWS AND IMPERFECTIONS AND SHALL BE FINISHED FLUSH WITH ITEM 1 WITHIN .005. THE SURFACE SHALL BE UNIFORMLY SMOOTH AS ACCOMPLISHED BY GRINDING OR EQUIVALENT TO THAT PRODUCED BY A STRAIGHT WRAP FINE WEAVE FABRIC. SURFACE IRREGULARITIES OVER A DEPTH OF .015 SHALL BE BLENDED INTO THE ADJACENT SURFACE.

6 <u>DIMENSIONAL STABILITY - DESIGN GOAL</u>. THE HOSE, WHEN FILLED WITH THE DIELECTRIC FLUID, SHALL MAINTAIN ITS DIAMETRICAL DIMENSIONS UNDER THE FOLLOWING CONDITIONS (SEE NOTES a, b, c).

(1) AT ROOM TEMPERATURE, DIELECTRIC FLUID PRESSURE 30 ± 2 PSI.

(2) AT ROOM TEMPERATURE, FLUID PRESSURE 2 PSI MINIMUM.

(3) AFTER 14 DAYS AT 125°F ± 5°F, IMMERSED IN OCEAN WATER, DIELECTRIC FLUID PRESSURE 30 ± 2 PSI. REPEAT DIMENSIONAL AND VISUAL INSPECTIONS UNDER CONDITIONS (1) AND (2).

<u>NOTES</u>:
(a) FLUID TO BE REPLENISHED AS NECESSARY TO MAINTAIN TEST PRESSURES.
(b) THE DIELECTRIC FLUID SHALL BE 050 760562 OF EXXON ISOPAR M SOLVENT.
(c) OCEAN WATER SHALL BE IN ACCORDANCE WITH ASTM D1141.

7 NO SURFACE IRREGULARITIES SHALL BE GENERATED WHEN THE ASSEMBLY IS SUBJECTED TO A TENSILE LOAD OF 800 LBS, FOR A PERIOD OF 10 MINUTES.

8 DIMENSIONS APPLY WITH ASSEMBLY SUBJECTED TO A 300 LB. TENSILE LOAD FROM A MINIMUM OF TEN MINUTES. THIS MEASUREMENT SHALL BE MADE 30 MINUTES ± 5 MINUTES AFTER REMOVING THE LOAD OF NOTE 7 (800 LBS.). TO REDUCE THE EFFECT OF FRICTION BETWEEN HOSE AND FLOOR OR BENCH THE HOSE SHALL BE LIFTED IN INCREMENTS OF 5 TO 6 FEET ONE INCREMENT AT A TIME ALONG ITS LENGTH DURING ELONGATION (LOADING) AND CONTRACTION (UNLOADING).

9. <u>ENVIRONMENTAL</u>. THE AM HOUSING SHALL BE DESIGNED TO MEET THE FOLLOWING TEMPERATURE CONDITIONS WITH NO SEPARATION BETWEEN PLIES, LEAKAGE, BLISTERING, OR OTHER DAMAGE DURING AND AFTER THE RESULTS.

OPERATIONAL	-2°C TO +40°C
STORAGE	-62°C TO +75°C

FURTHER, THE AM HOUSING SHALL BE FUNGUS RESISTANT PER MIL-STD-810, AND THE BUTYL LAYER OF THE HOUSING SHALL PROVIDE OZONE RESISTANCE PER MIL-STD-417.

NOTES CONTINUED ON SHEET 2

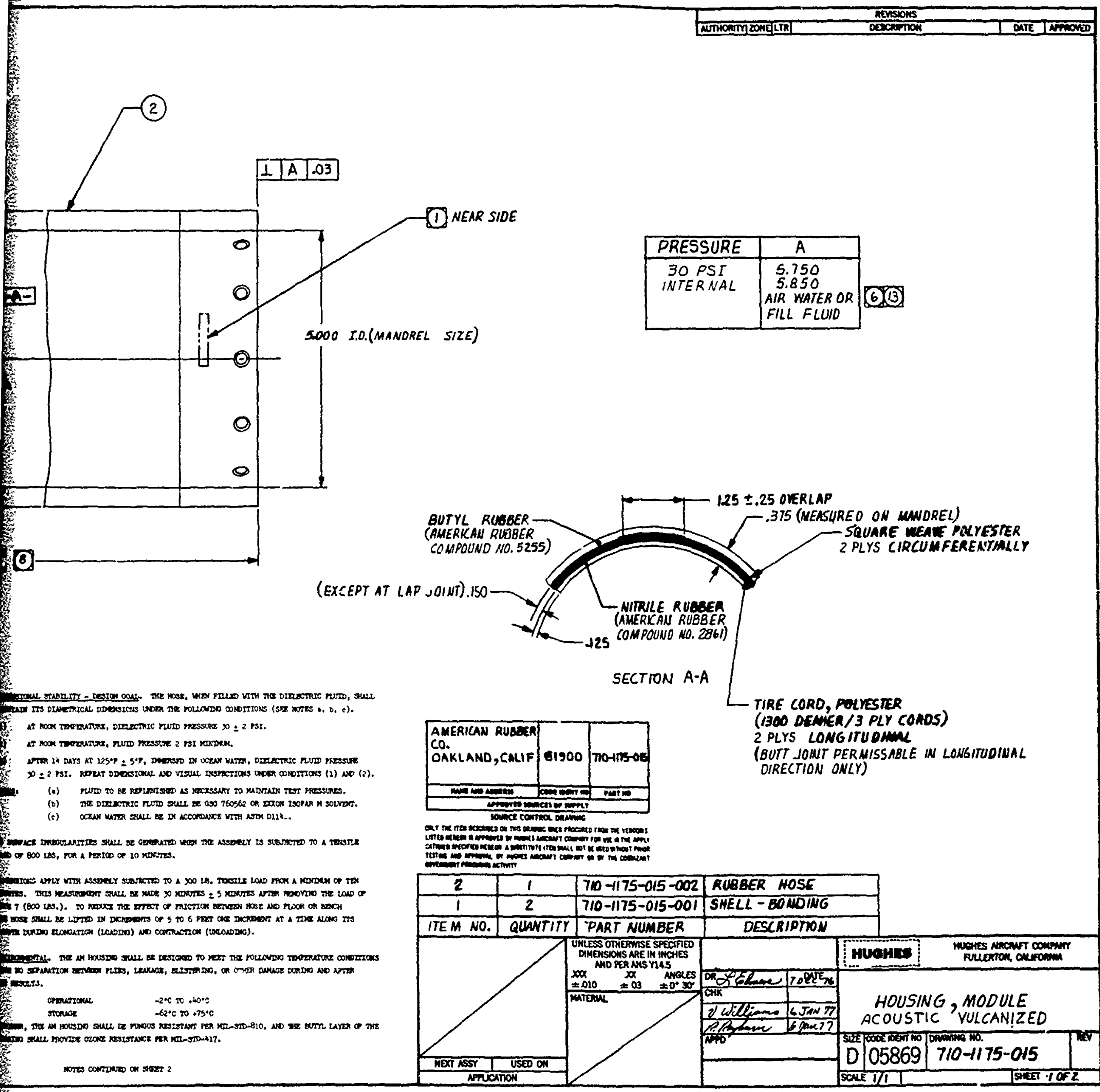


Figure 13. FAM Hose – Engineering Drawing

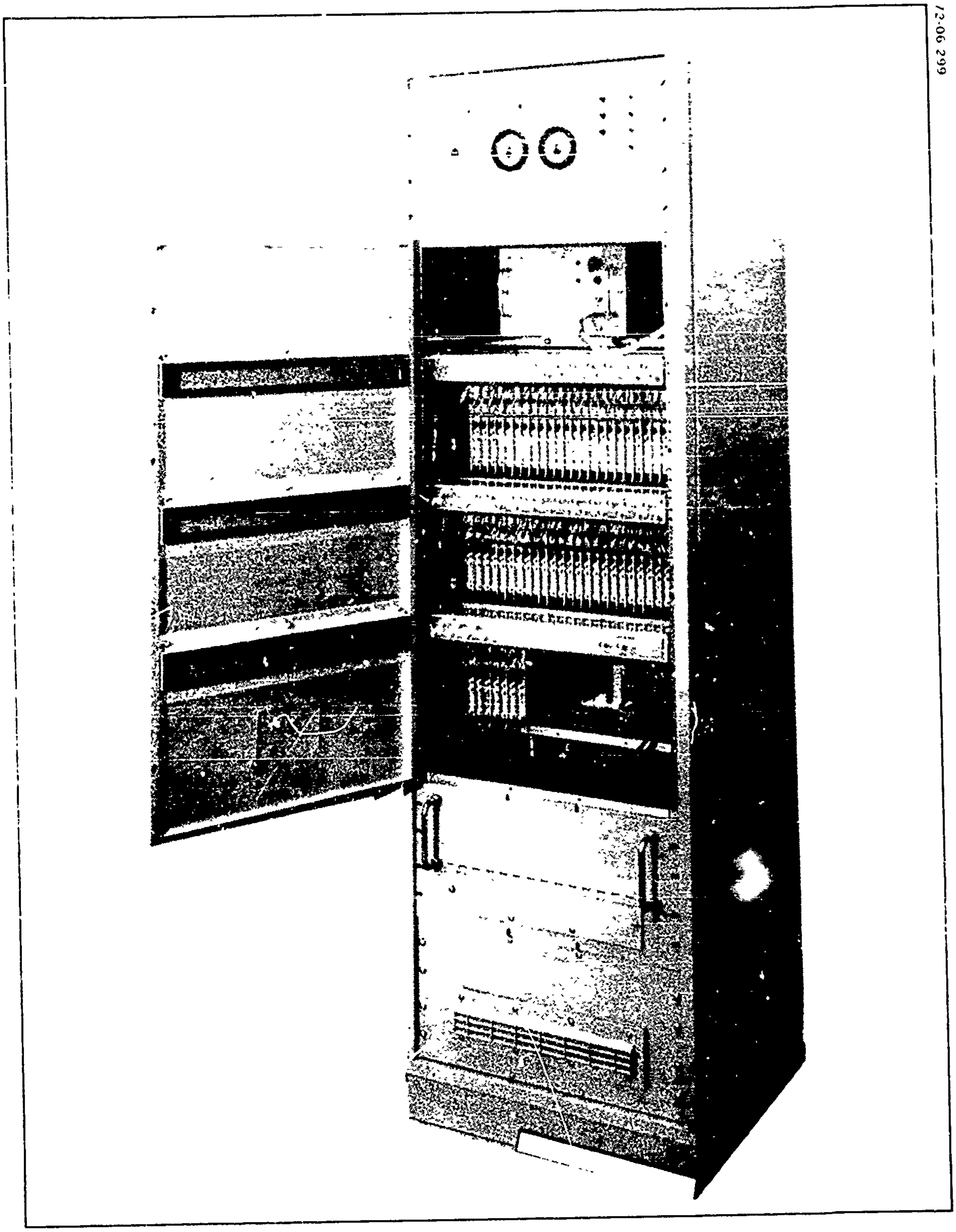


Figure 14. Telemetry Receiver

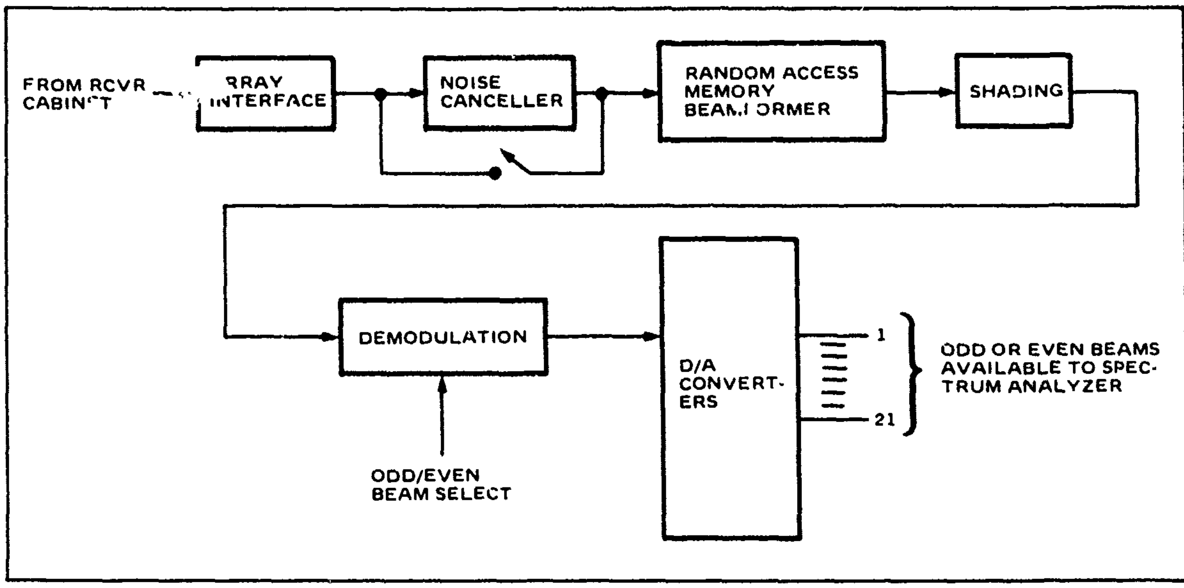


Figure 15. Beamformer Functional Block Diagram

BEAM MRAs AND ANGULAR COVERAGES

BEAM NUMBER	θ_{MRA} (DEG RE F'WD E.F.)	BEAM CROSSOVER TO CROSSOVER (DEG)	BEAM COVERAGE (DEGREES)
1	90.000	-2.866 TO 2.866	5.732
2	84.261	2.866 TO 8.627	5.761
3	78.463	8.627 TO 14.476	5.849
4	72.542	14.476 TO 20.487	6.011
5	66.422	20.487 TO 26.744	6.257
6	60.000	26.744 TO 33.367	6.623
7	53.130	33.367 TO 40.542	7.175
8	45.573	40.542 TO 48.590	8.048
9	36.870	48.590 TO 58.212	9.622
10	25.842	58.212 TO 71.805	13.593
11	0	71.805 TO 108.195	36.390

73957-6

Figure 16. Beam Pattern Data

Figure 17. Beamformer Installed on R/V Harris

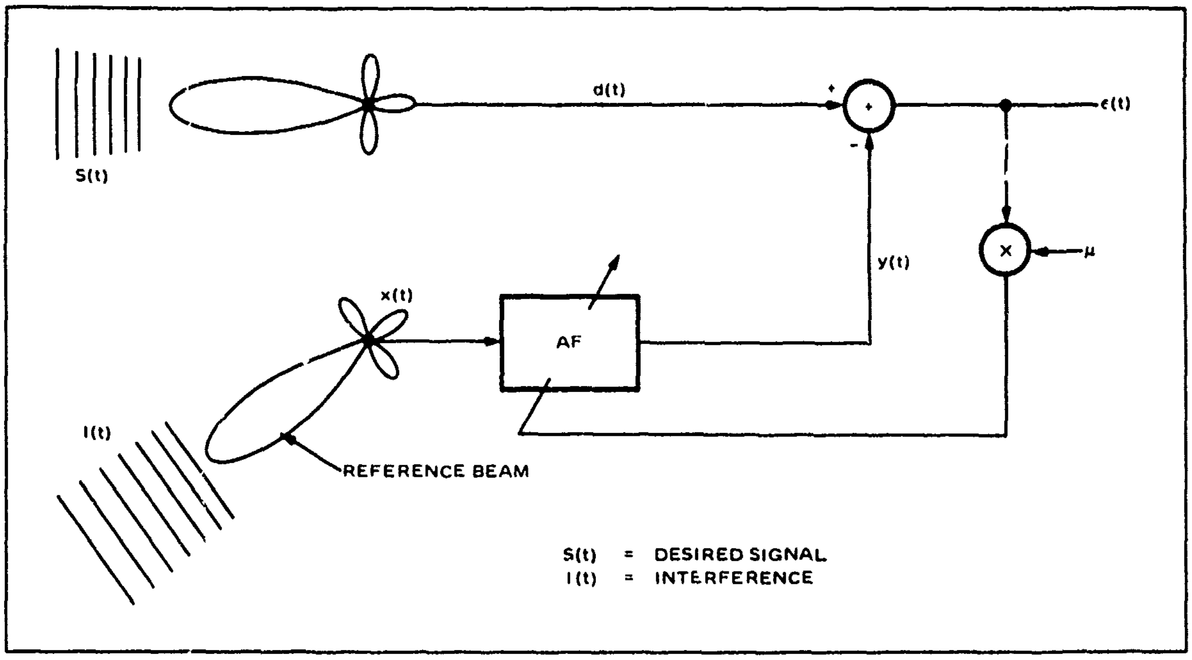


Figure 18. Adaptive Noise Canceller (Minipro)

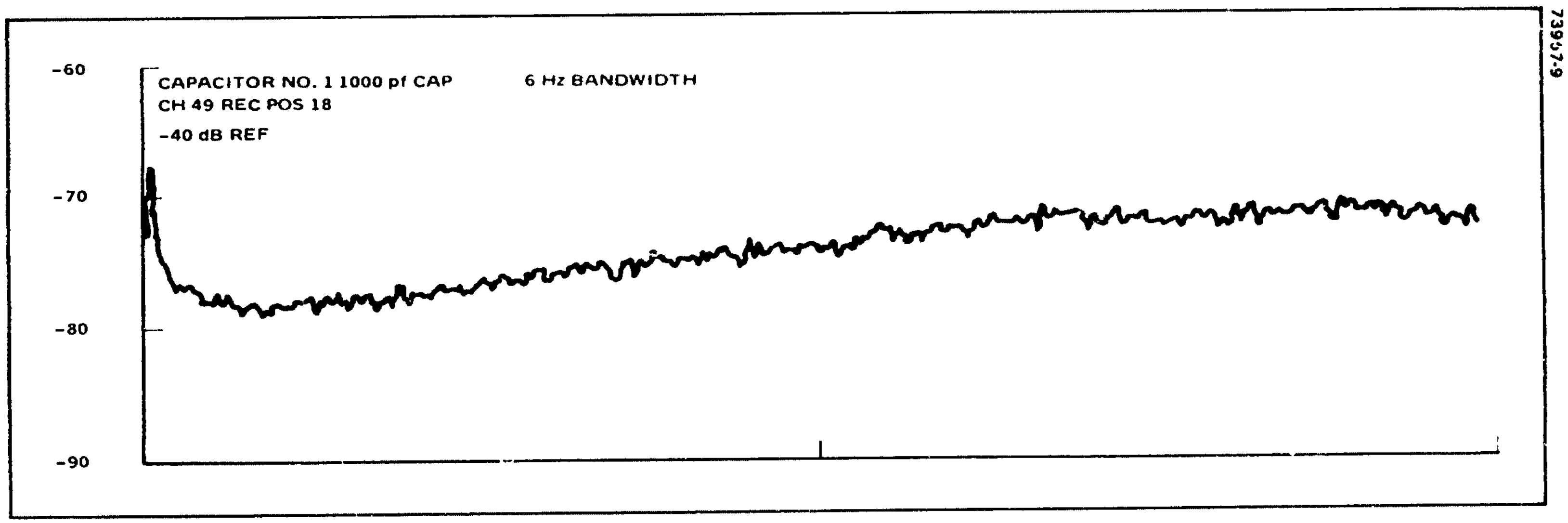


Figure 19. Electronic Self Noise (Rx Out)

RCVR POSITION	CHANNEL NO.	R.F. FREQUENCY	R.F. LEVEL	SENSOR
1	20	1671.61	-37.2	F-1
2	53	1374.63	-33.0	TENS
3	21	1662.03	-36.8	F-2
4	54	1326.73	-34.0	PRESS
5	22	1552.45	-37.0	F-3
6	51	1920.69	-34.8	F.C. ACC #1
7	23	1642.87	-37.0	F-4
8	52	1911.11	-34.6	F.C. HYD
9	24	1633.29	-37.4	F-5
10	57	1997.33	-34.8	F.C. HYD
11	25	1623.71	-37.2	F-6
12	58	1987.75	-35.5	F.C. HYD
13	26	1614.13	-38.2	F-7
14	61	1959.01	-36.5	F.C. HYD
15	27	1604.55	-38.8	F-8
16	62	1939.85	-37.7	F.C. ACC #2
17	30	1575.81	-39.9	F-9
18	49	1393.79	-38.0	CAP #1
19	31	1566.23	-40.2	*F-10
20	43	1451.27	-39.5	*#21 HYD
21	32	1556.65	-40.4	F-11
22	44	1441.69	-40.2	#22 HYD
23	33	1547.07	-40.0	F-12
24	45	1432.11	-40.0	*#23 HYD
25	34	1537.49	-39.5	F-13
26	46	1422.53	-39.5	#24 HYD
27	48	1403.37	-38.5	#25 HYD
28	35	1527.91	-38.8	F-14
29	50	1384.21	-38.0	CAP #2
30	36	1518.33	-38.8	F-15
31	1	1901.53	-41.5	A.C. ACC #1
32	37	1508.75	-38.5	F-16
33	2	1891.95	-41.1	A.C HYD
34	38	1499.17	-38.7	F-17
35	16	1748.25	-41.7	A.C. HYD
36	39	1489.59	-38.5	F-18
37	17	1719.51	-41.5	A.C. HYD
38	40	1480.01	-38.2	F-19
39	18	1709.93	-42.0	A.C. HYD
40	42	1460.85	-39.0	F-20
41	19	1681.19	-41.4	A.C. ACC #2

ARRAY CONFIGURATION

NC — VPM — TEN — PRESS — SIM VIM — FWD CONT — FAM — AFT CONT

R.F. LEVELS MEASURED @ DIST BUSS WITH ATTEN BETWEEN DECOUPLER AND CABLE EQUALIZER

ARRAY VOLTAGE — 150V
ARRAY CURRENT — 1.75 A

*FOAM MOUNTED HYDROPHONE

73957-10

Figure 20. Receiver Data

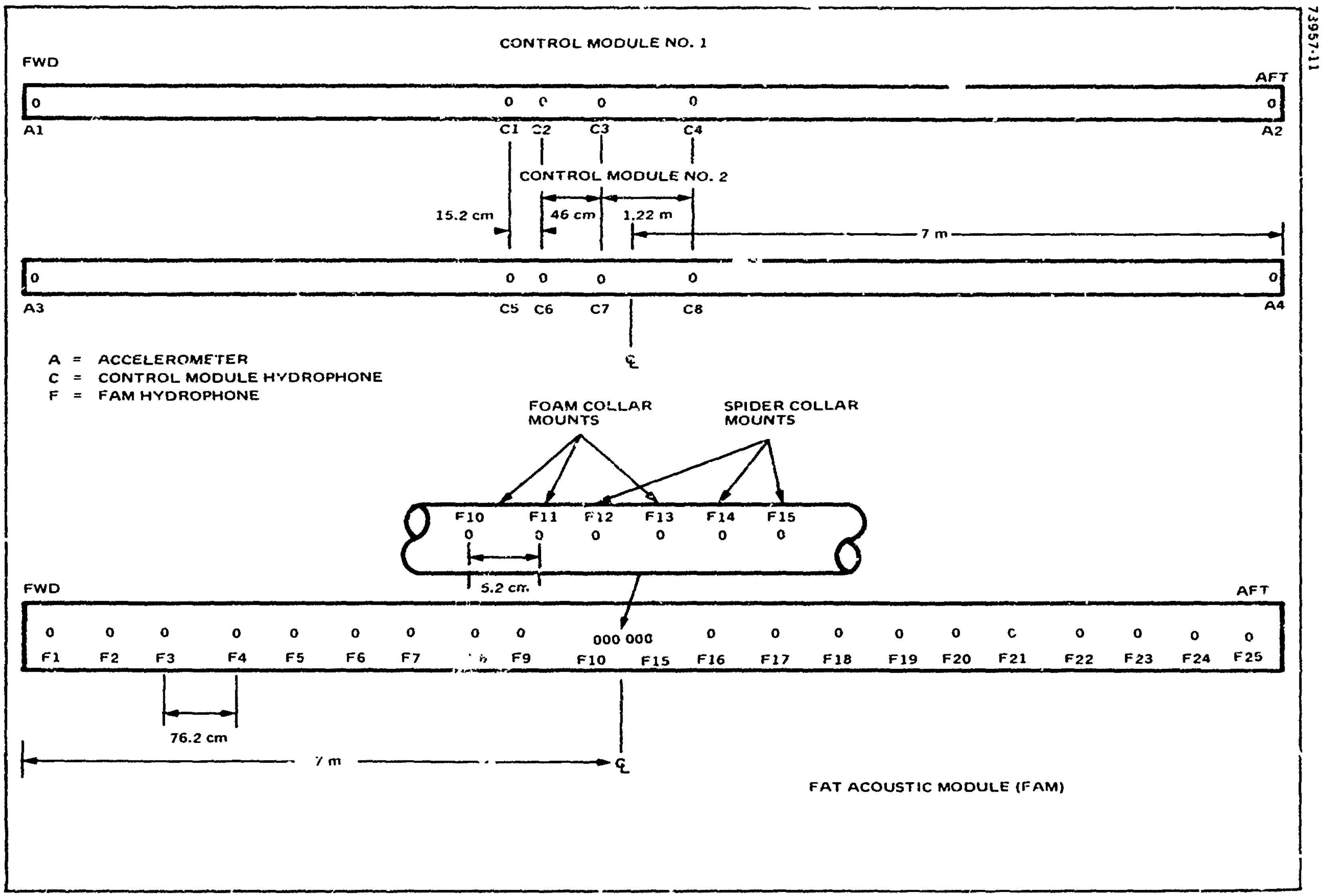


Figure 21. Sensor Deployment

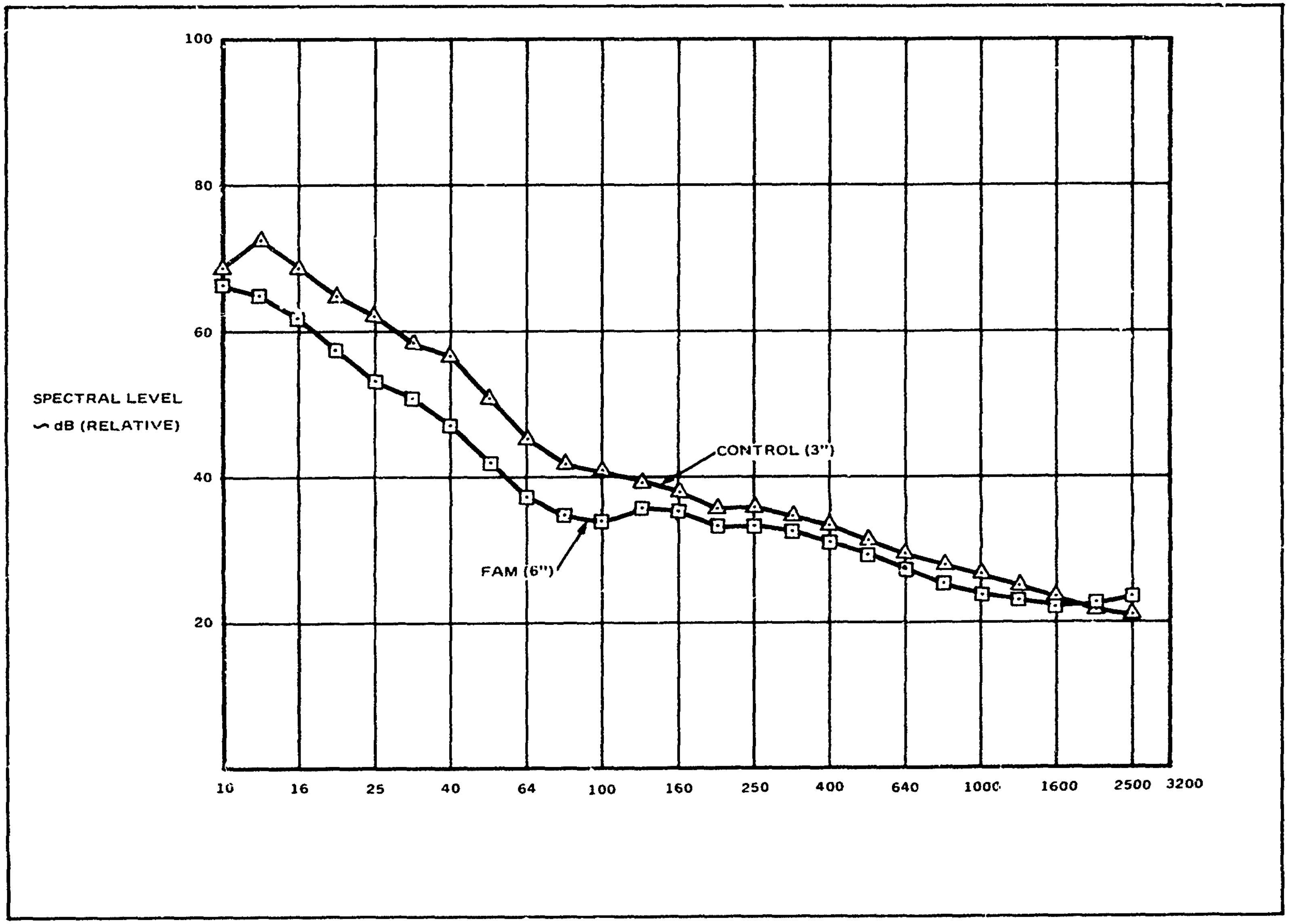


Figure 22. Array Self Noise (FAM versus Control) V = 6 Kts

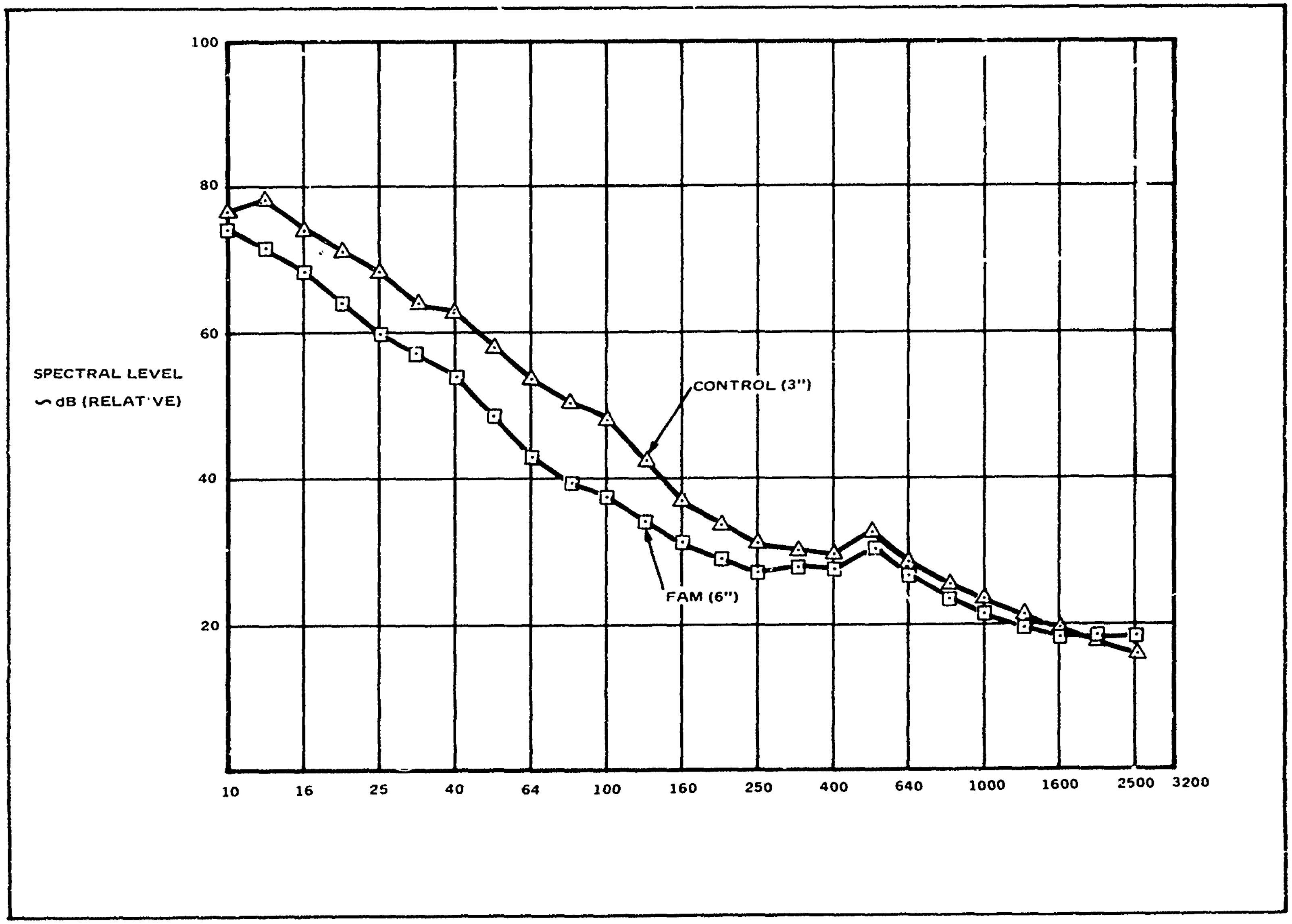


Figure 23. Arra'/ Self Noise (FAM versus Control) V = 9 Kts

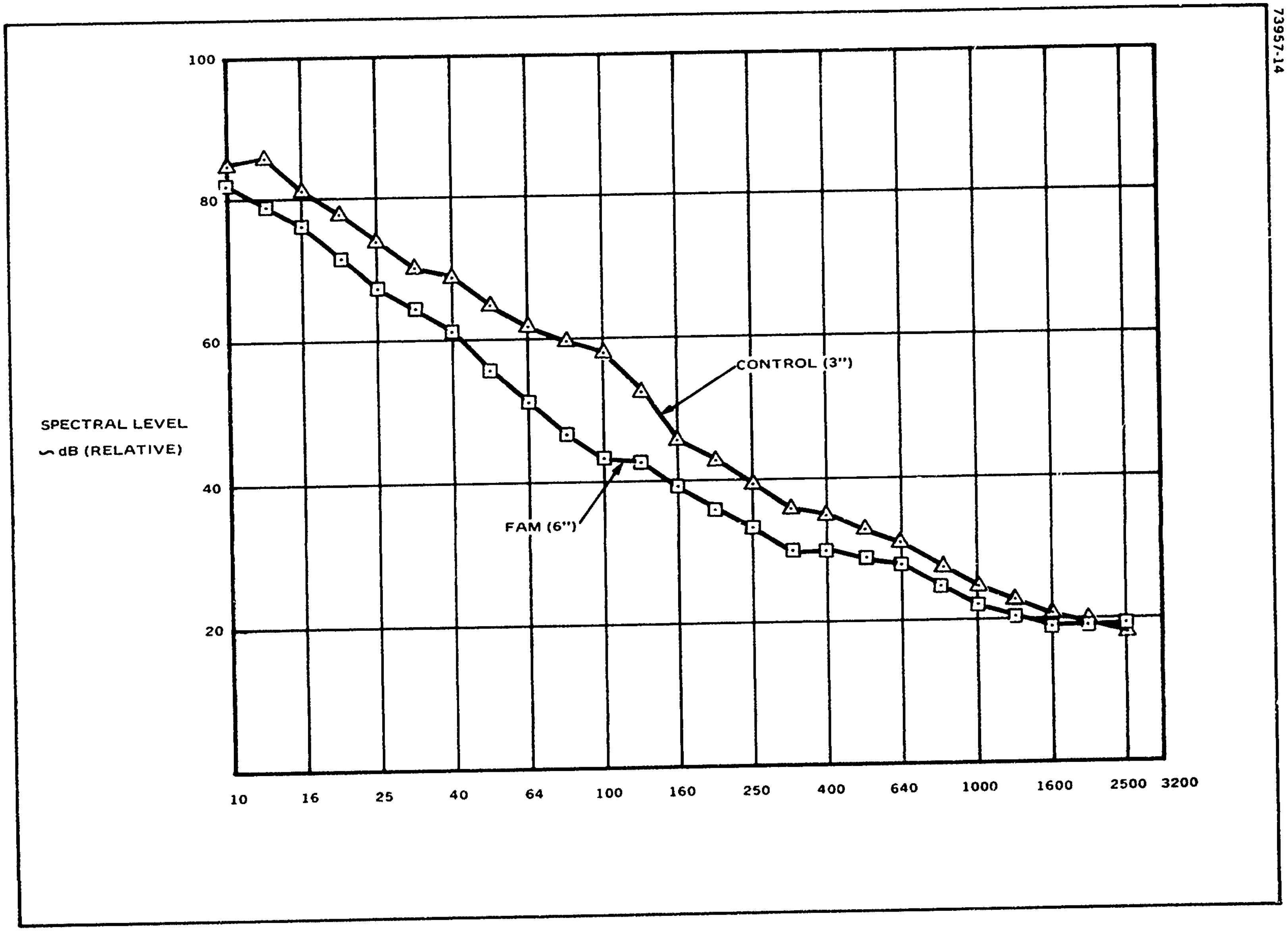


Figure 24. Array Self Noise (FAM versus Control) V = 12 Kts

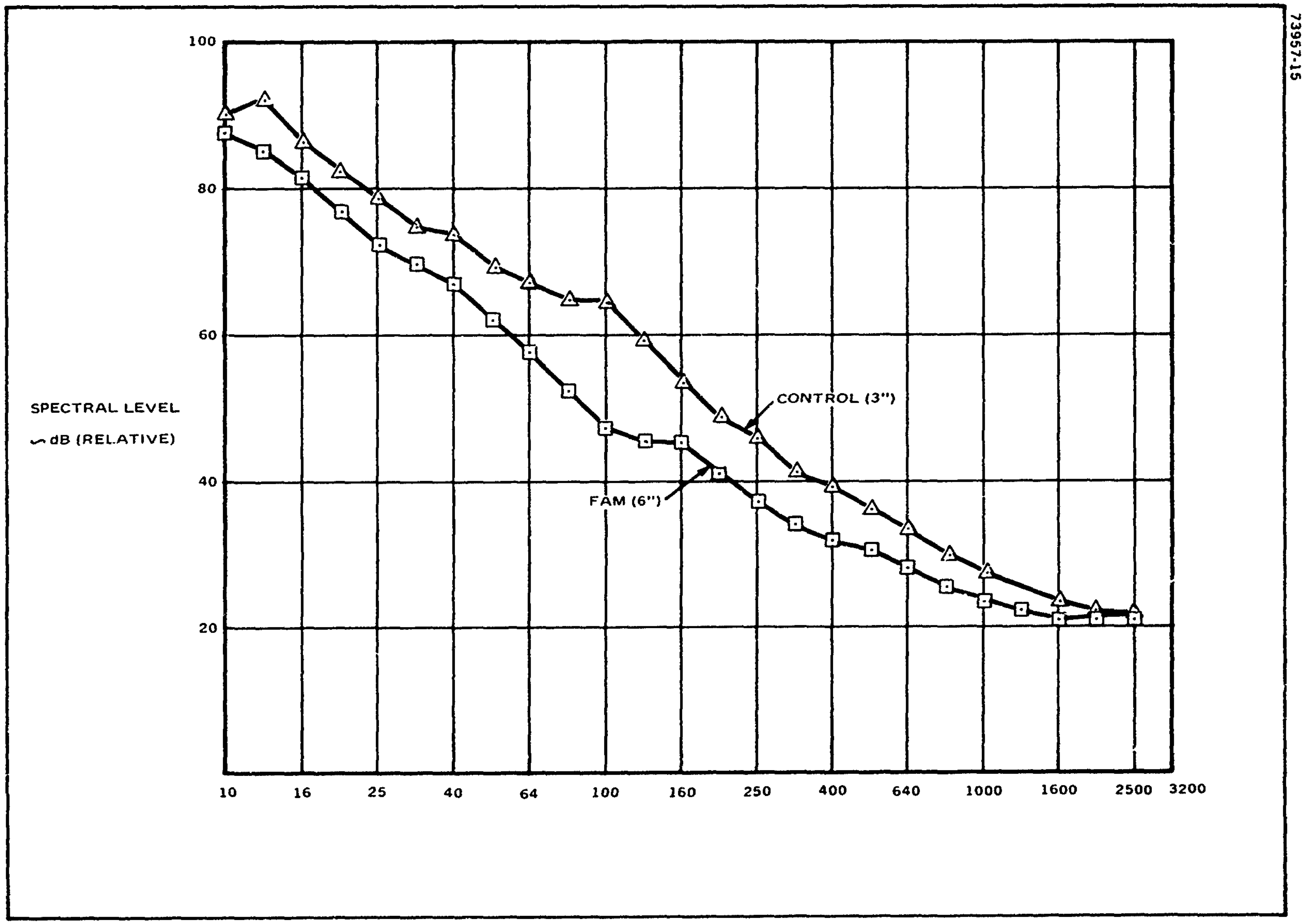


Figure 25. Array Self Noise (FAM versus Control) V = 15 Kts

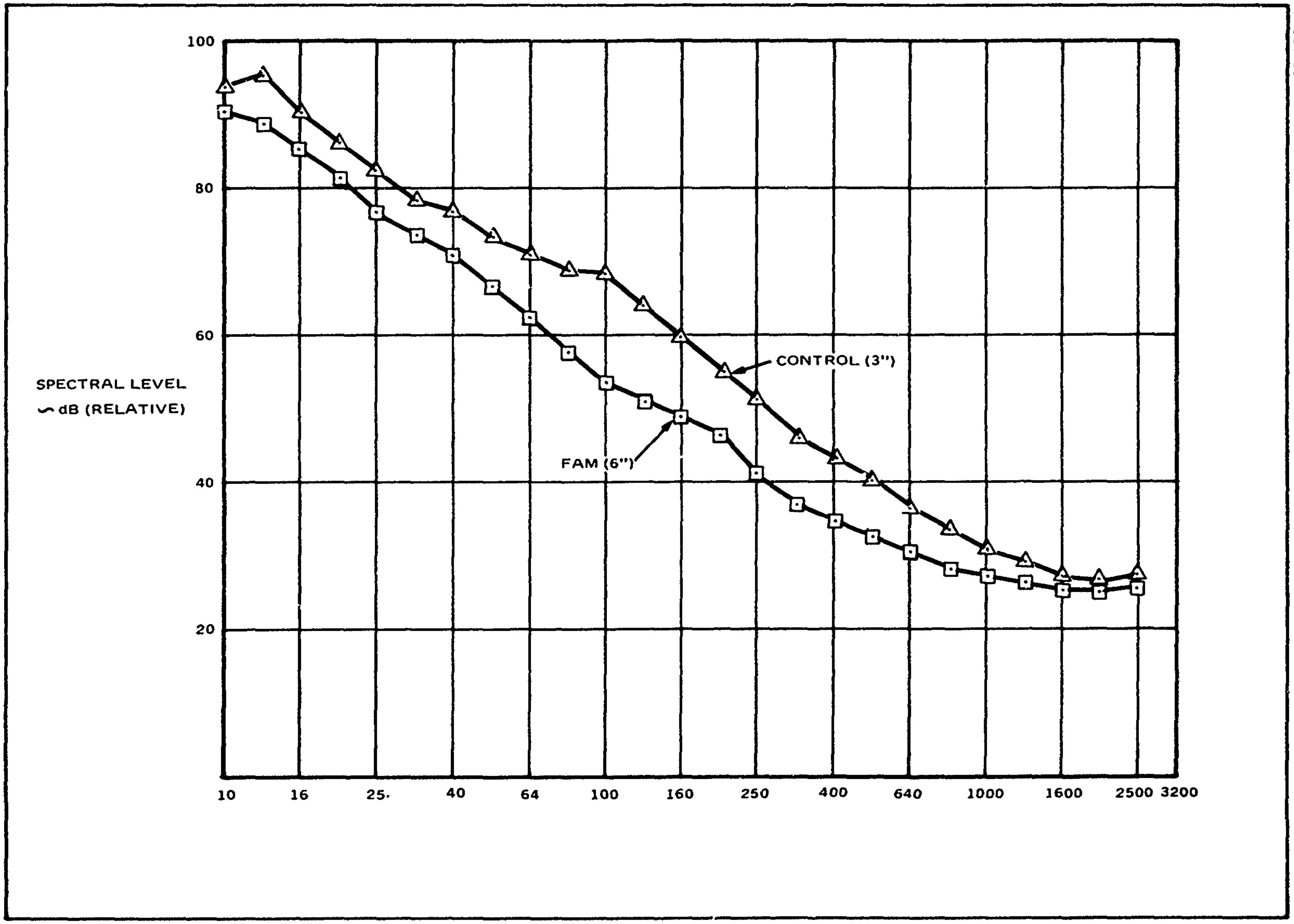


Figure 26. Array Self Noise (FAM versus Control) V = 18 Kts

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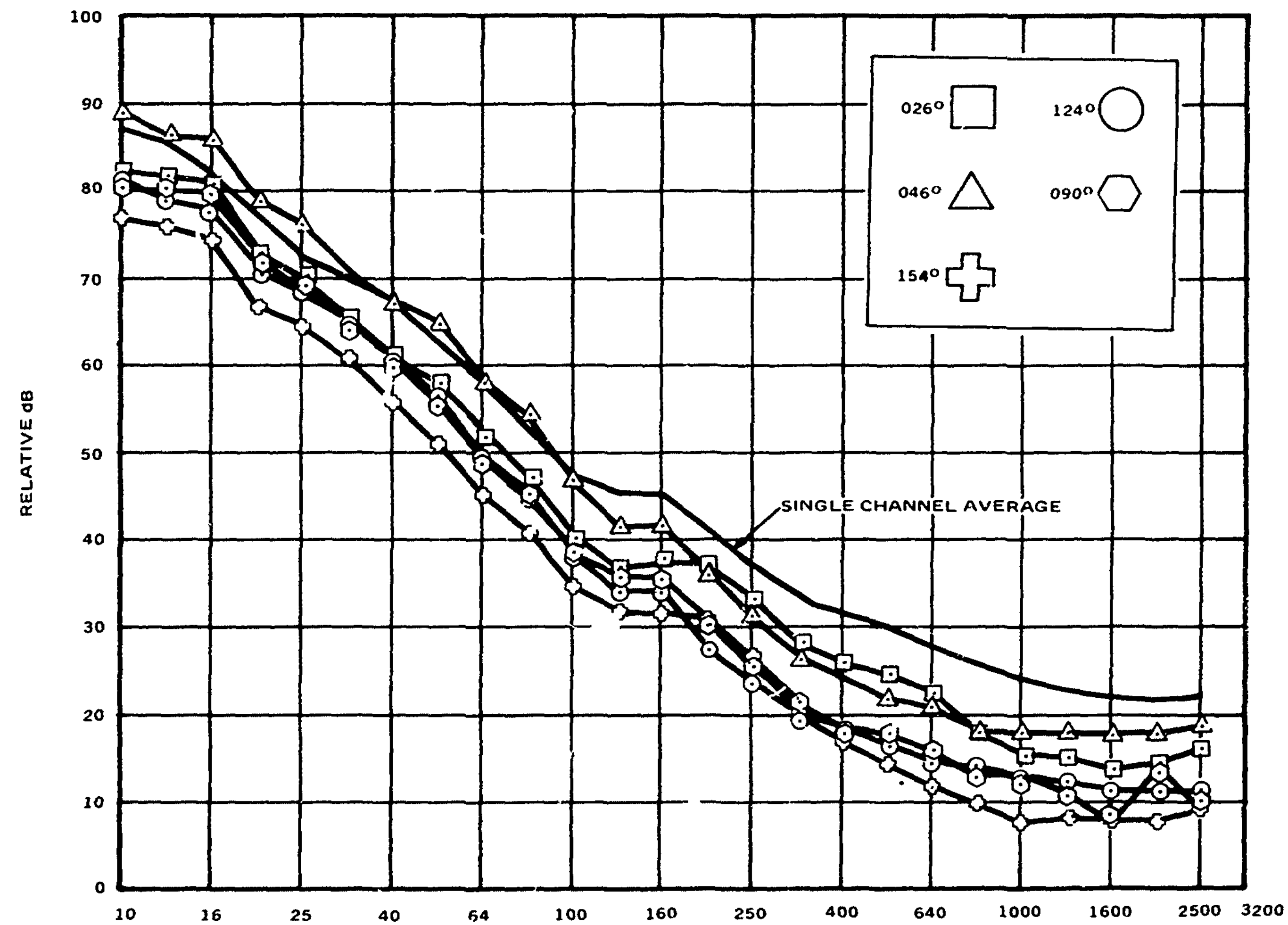

Figure 27. Beamformer Output Self Noise (15 Kts)

73957-18

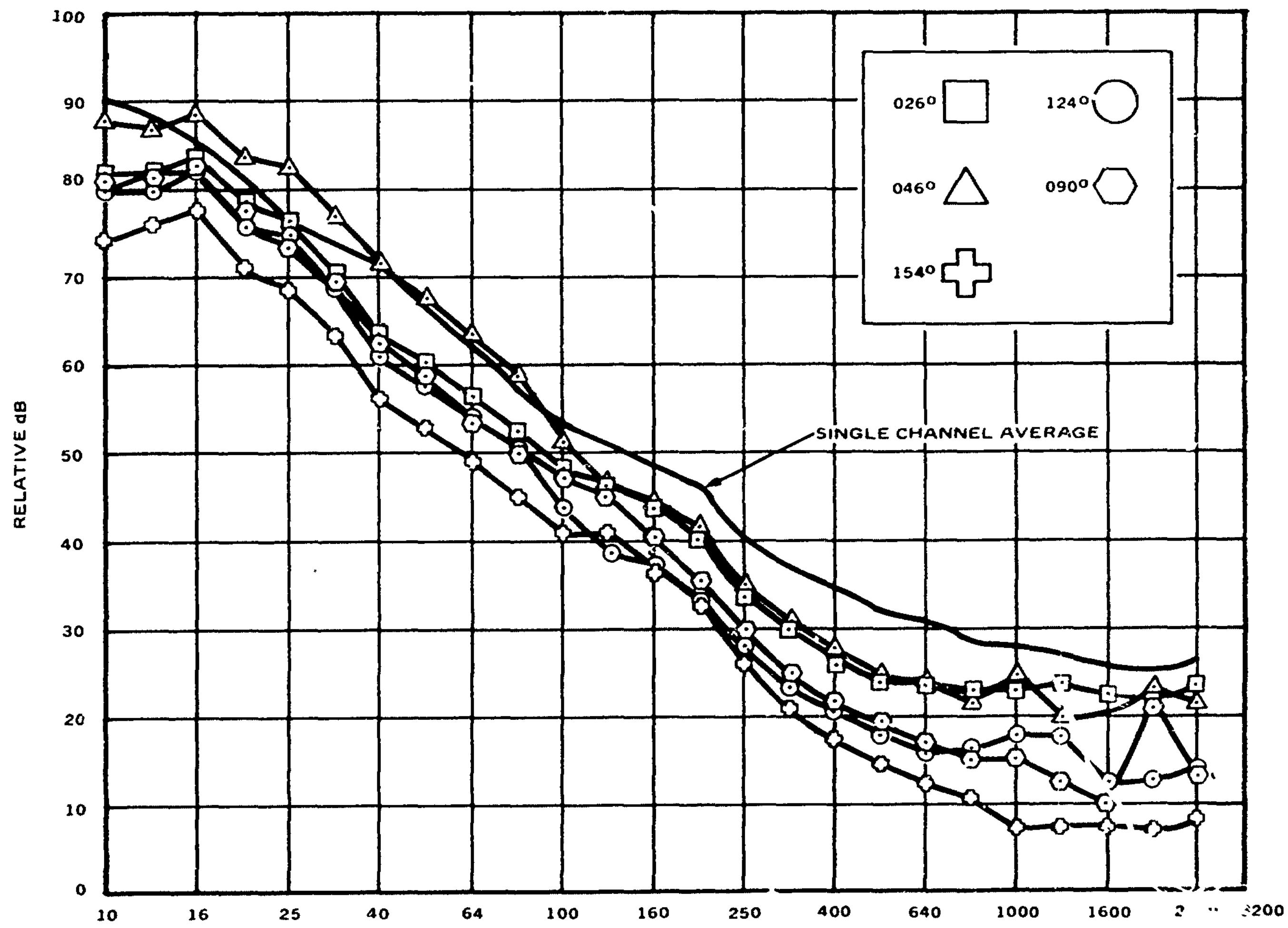

Figure 28. Beamformer Output Self Noise (18 Kts)

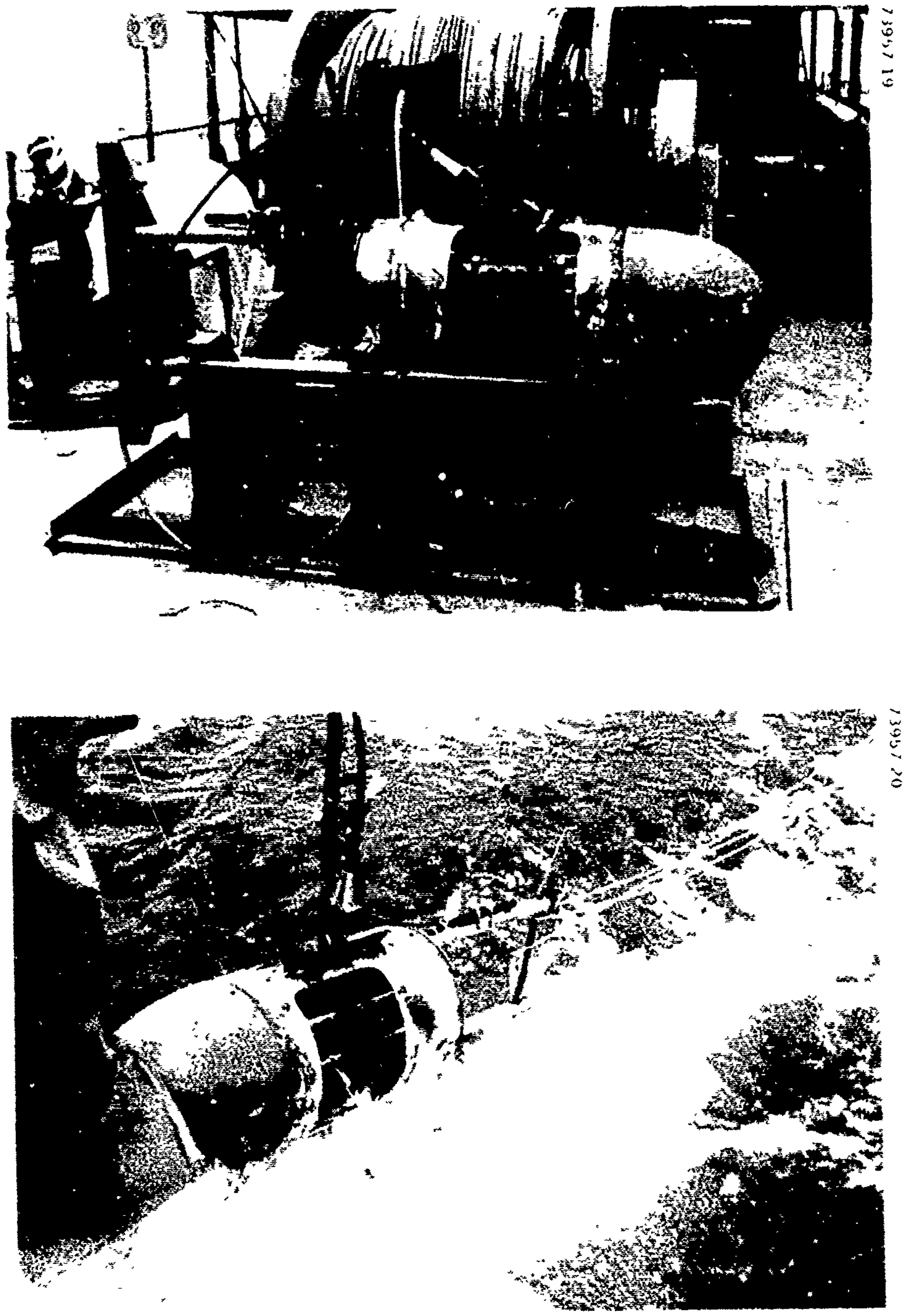

Figure 29. HX-90 Sound Source

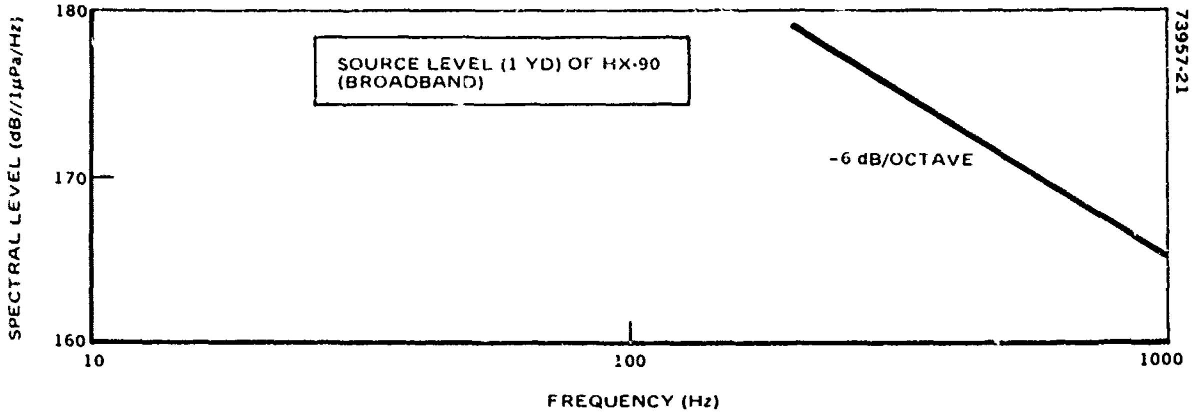

Figure 30. HX-90 Output Spectrum

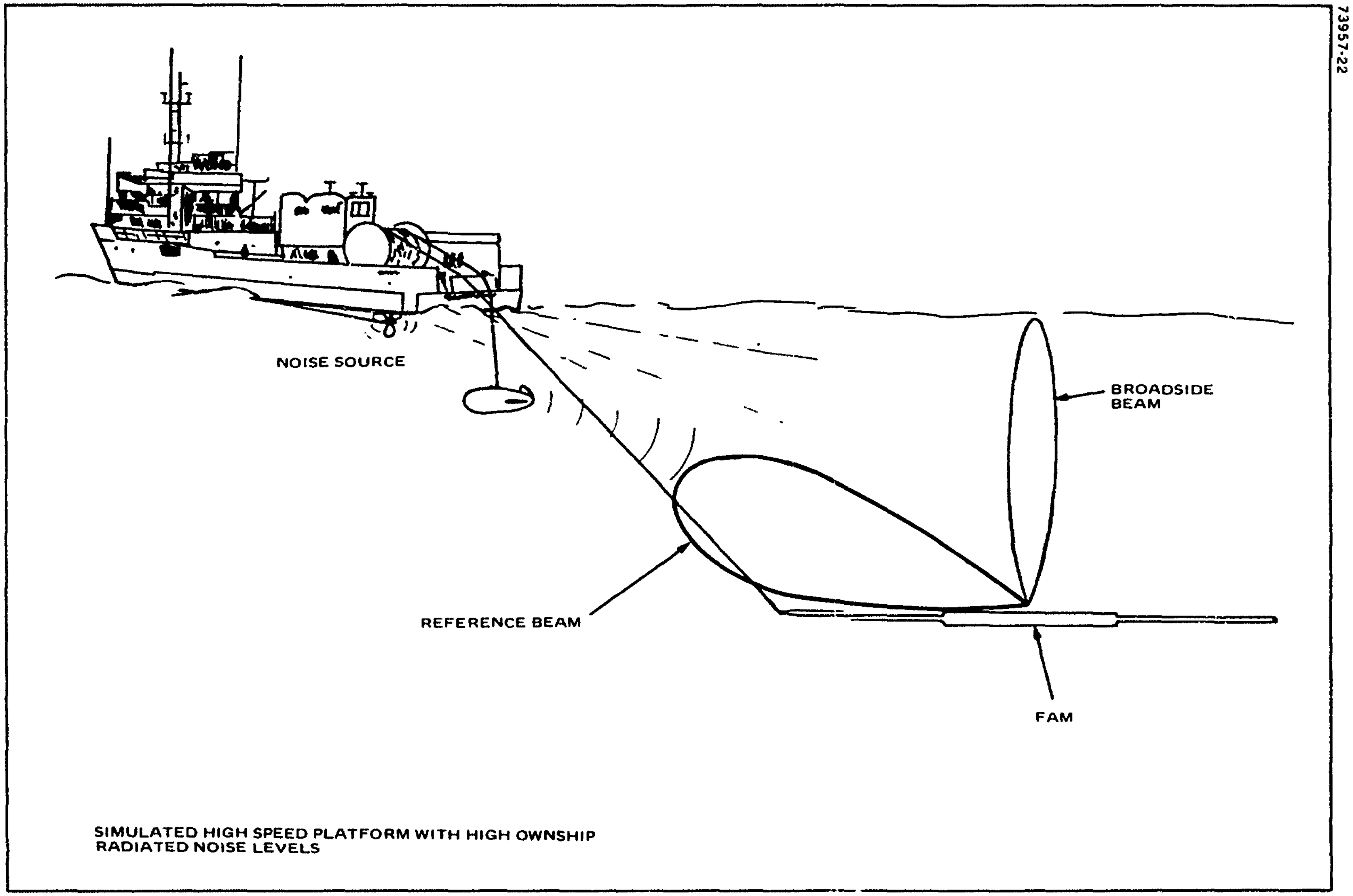

Figure 31. Noise Source (HX-90) Towing Geometry

73957-23

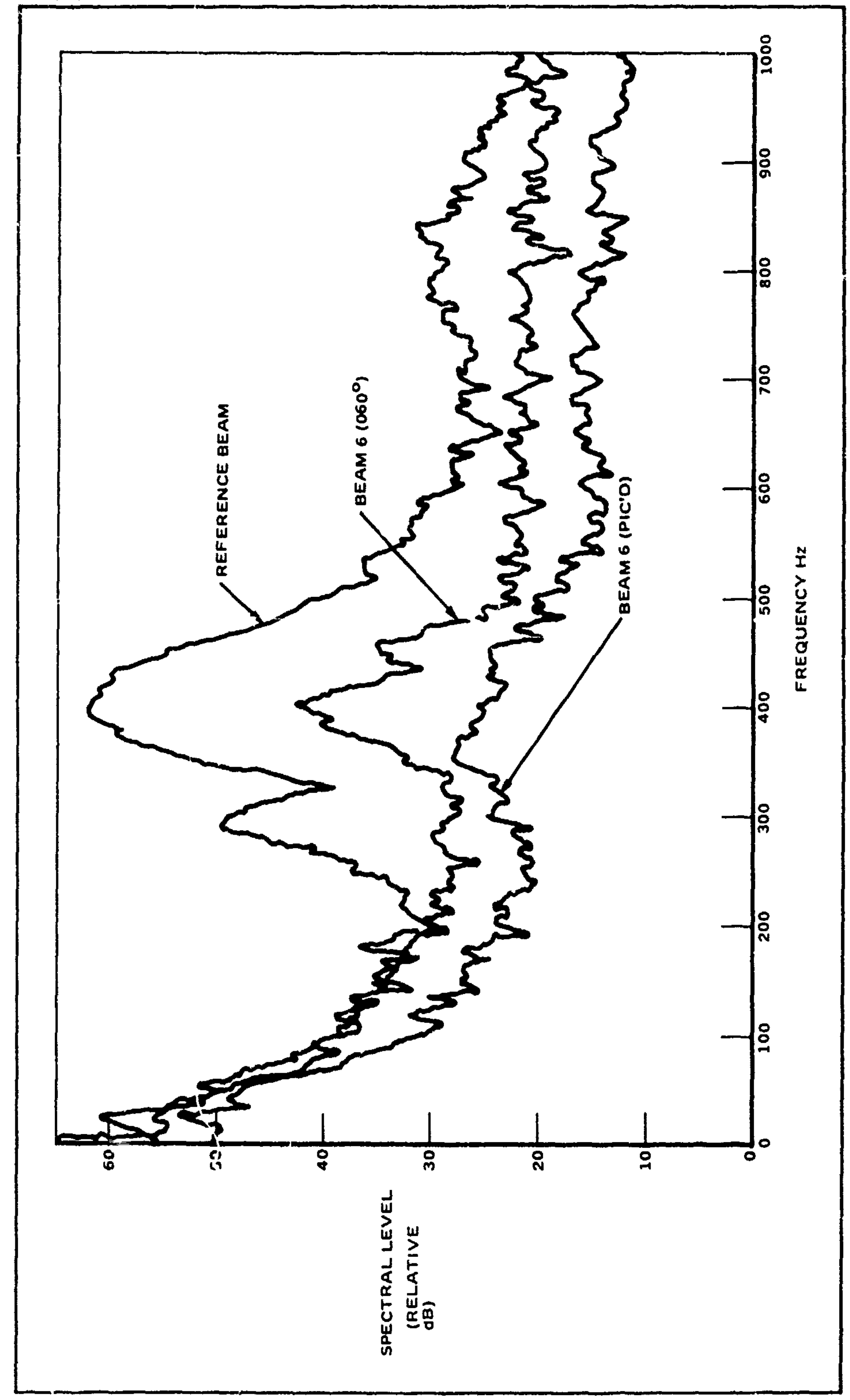

Figure 32. Minipro Adaptive Noise Canceller Results (Broadband)

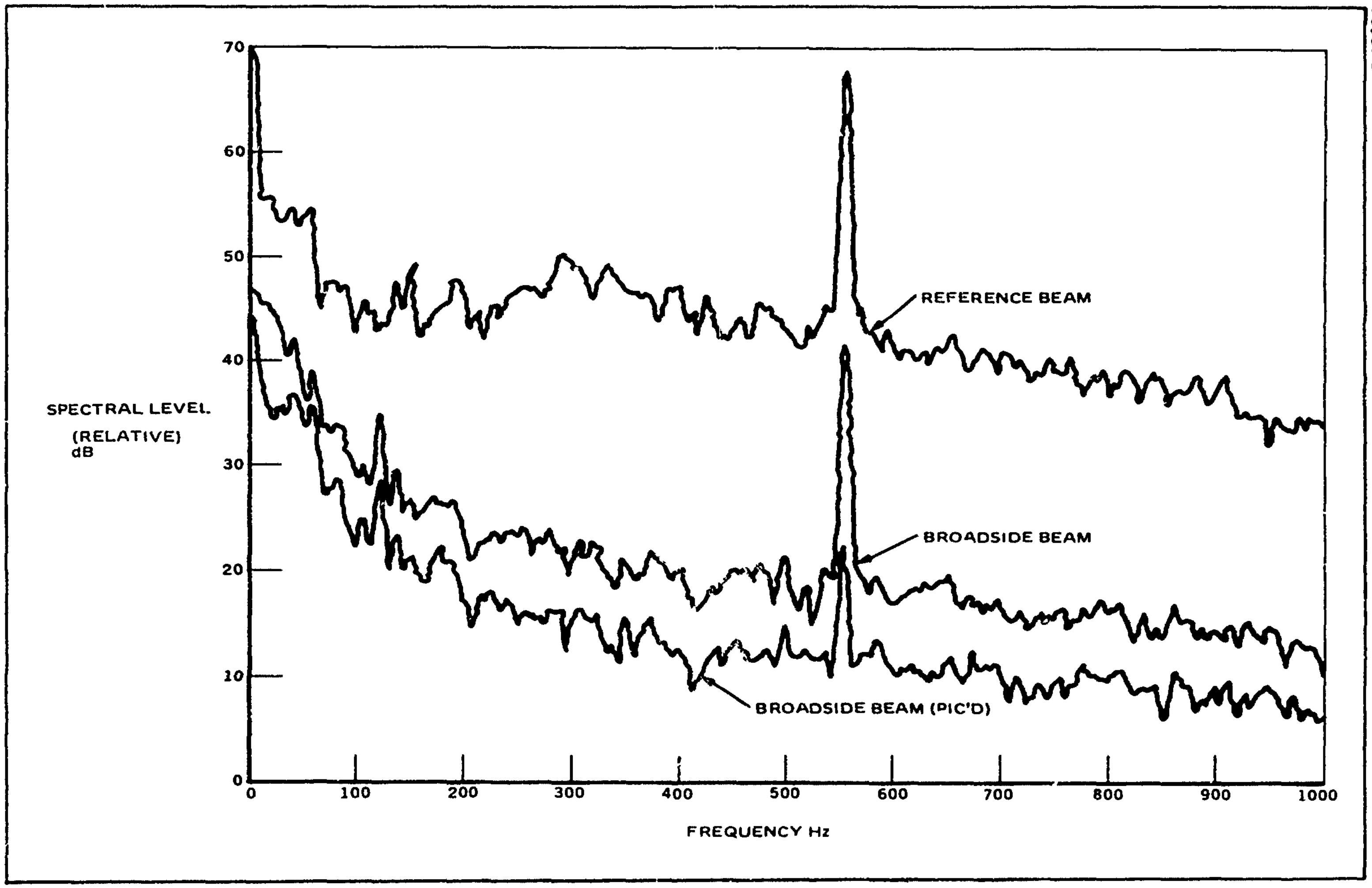

Figure 33. Minipro Adaptive Noise Canceller Results (Narrowband)

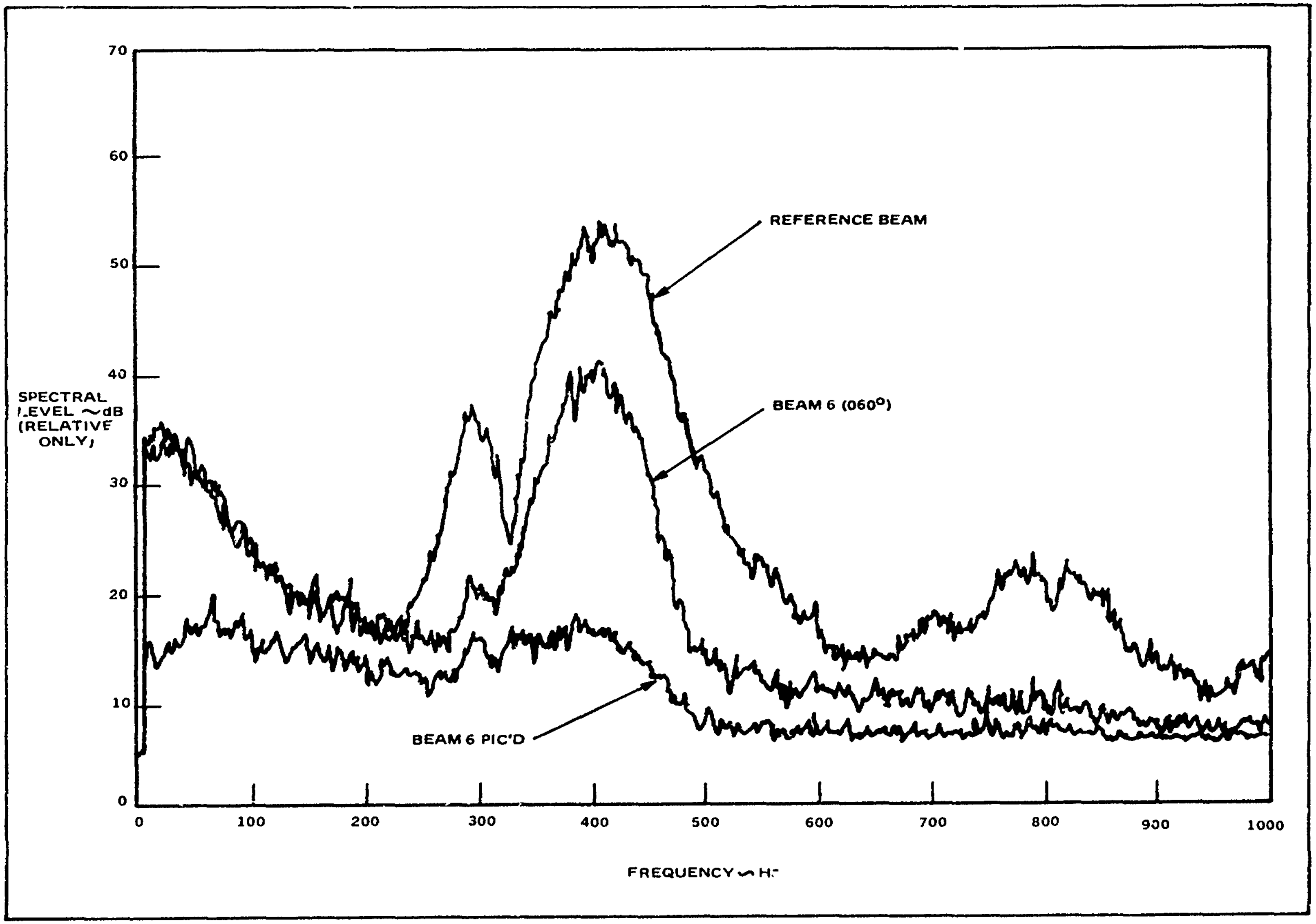

Figure 34. Minipro Adaptive Noise Canceller Results (Broadband) – Post Sea Test

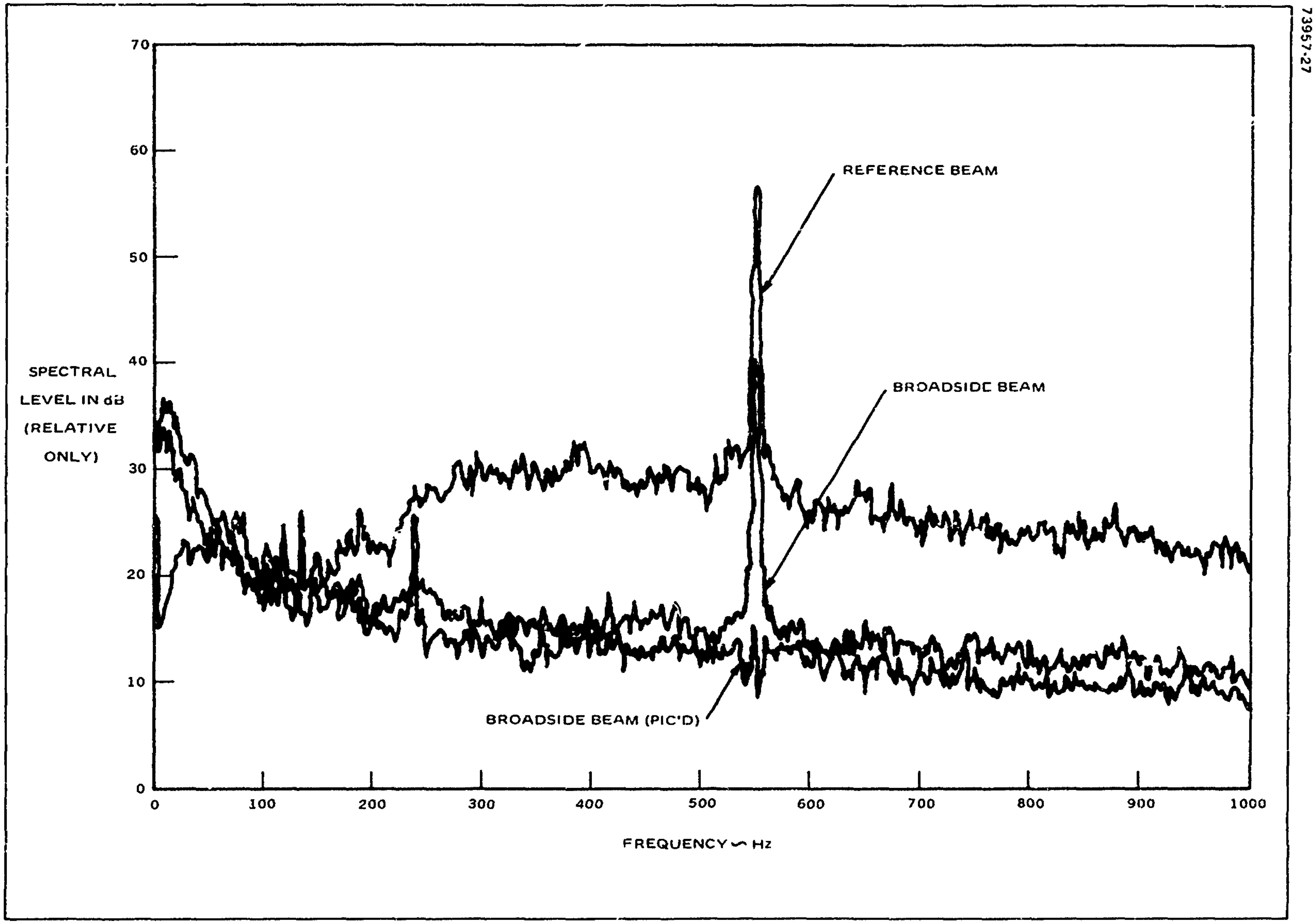

Figure 35. Minipro Adaptive Noise Canceller Results (Narrowband) – Post Sea Test

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

During the reporting period (FY 1977), a High Speed Towed Array System (HSTAS ~~- see Figure 1)~~ was conceived, designed, and fabricated. The system was successfully sea tested in July of 1977 in Exuma Sound in the Bahamas aboard the R/V Harris.

In addition to the test being successful from the point of view of equipment operability at sea, the following program goals were

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achieved:

a) The self noise results ~~(shown in Figures 22-26)~~ revealed that the 6 inch diameter module (FAM) was always quieter than the 3 inch modules, reaching a peak differential of approximately 15 dB in the frequency range between 80 Hz and 250 Hz at 18 knots tow-speed. ~~(Figure 26)~~ This general trend, which has been verified ~~experimentally,~~ tends to support the theory set forth by Chase[1] in reference to the dependence of array self noise on diameter (see Section IV).

b) The demonstration (at sea) of the ability to eliminate ownship radiated noise interference from beam outputs by means of an adaptive filter employed as a noise canceller. Specifically, in the case of a broadband interfering signal, a maximum cancellation of 15 dB was achieved (Figure 32), while for the narrowband case the cancellation was 18 dB (Figure 33). For this latter effort, the R/V Harris was augmented acoustically by towing the HX-90 noise source.

The array self noise and the noise canceller results taken together thus provide a systems approach to the problem of utilizing a towed array behind a high speed platform which injects large amounts of acoustic energy into the water. Further testing and evaluation of the system at higher tow speeds is necessary to demonstrate the effectiveness of the HSTAS concept.